Foraminiferal ecology of contemporary isolation basins in Northwest Scotland

Laidler, Philip Damien

Foraminiferal Ecology of Contemporary Isolation Basins in Northwest Scotland

Volume Two:

Figures, Plates, and Appendices

Philip Damien Laidler

Thesis submitted for the degree of Doctor of Philosophy.

Department of Geography,

University of Durham

January 2002

List of Contents

List of Figures and Plates

List of Plates

CHAPTER FOUR

List of Tables

APPENDIX THREE

APPENDIX FOUR

APPENDIX FIVE

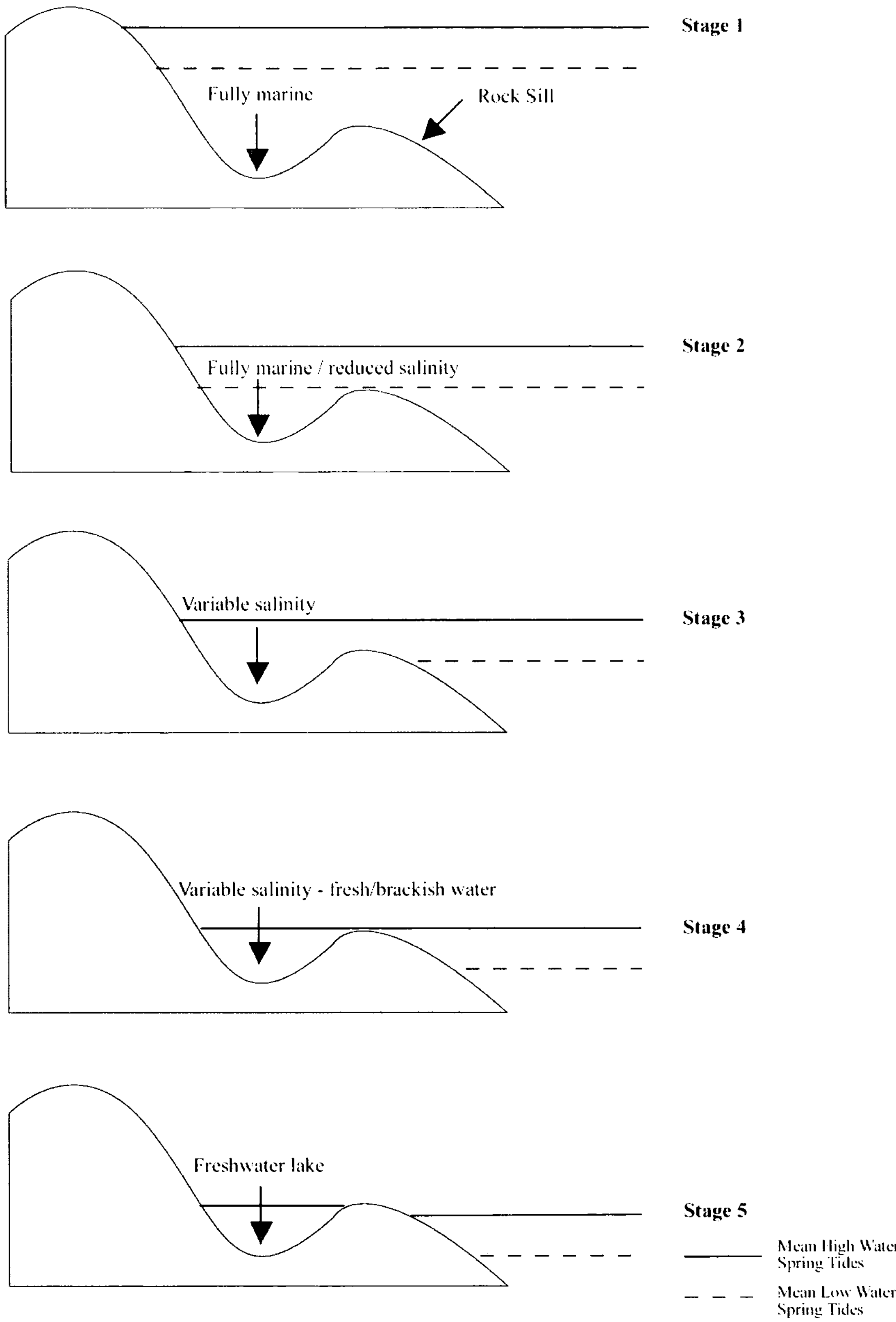


Figure 2.1: Schematic representation of an isolation basin during a fall in relative sea-level (Lloyd, 2000). Stages 1 – 5 correspond with the sequence outlined in Figure 2.2.

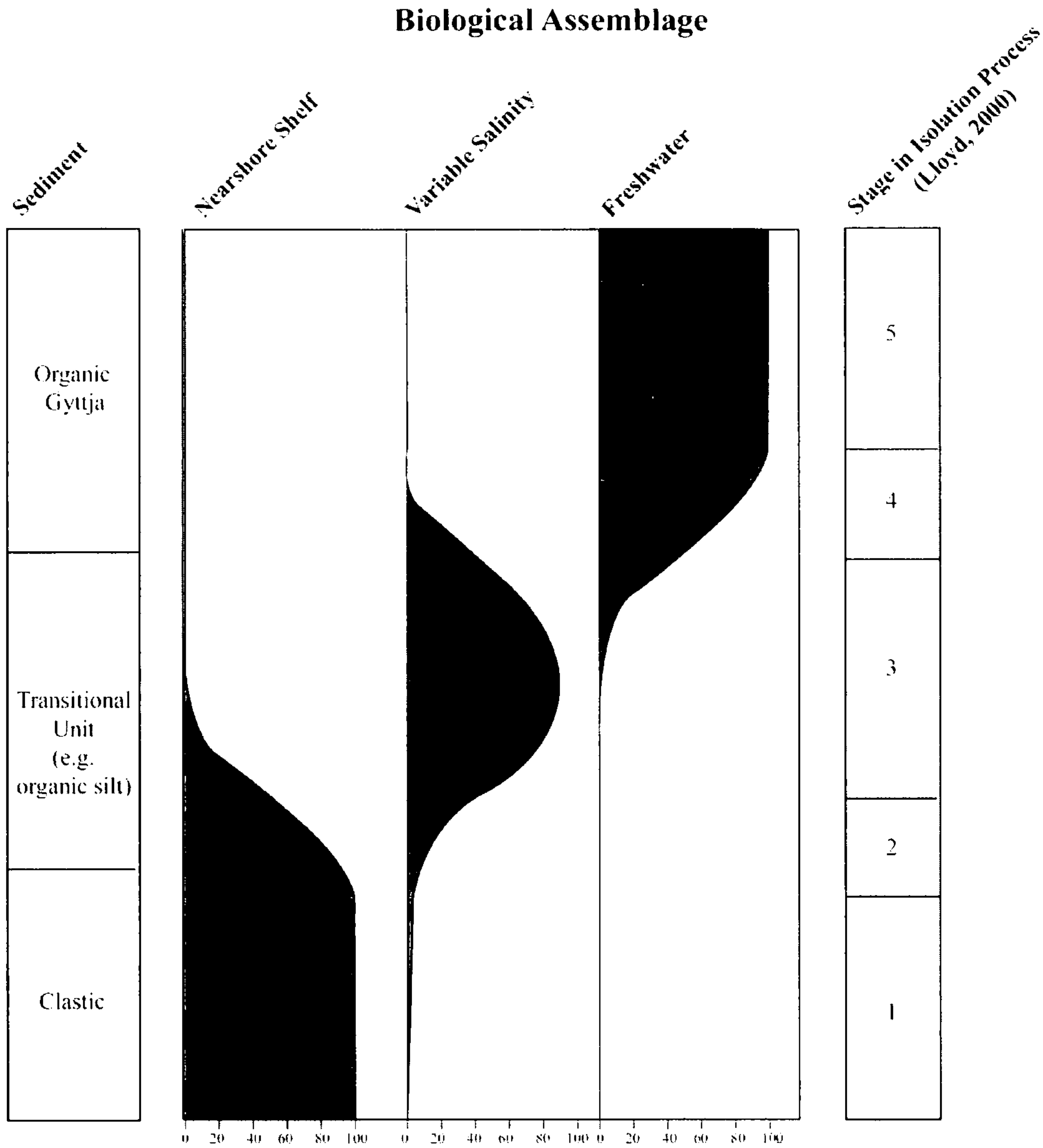
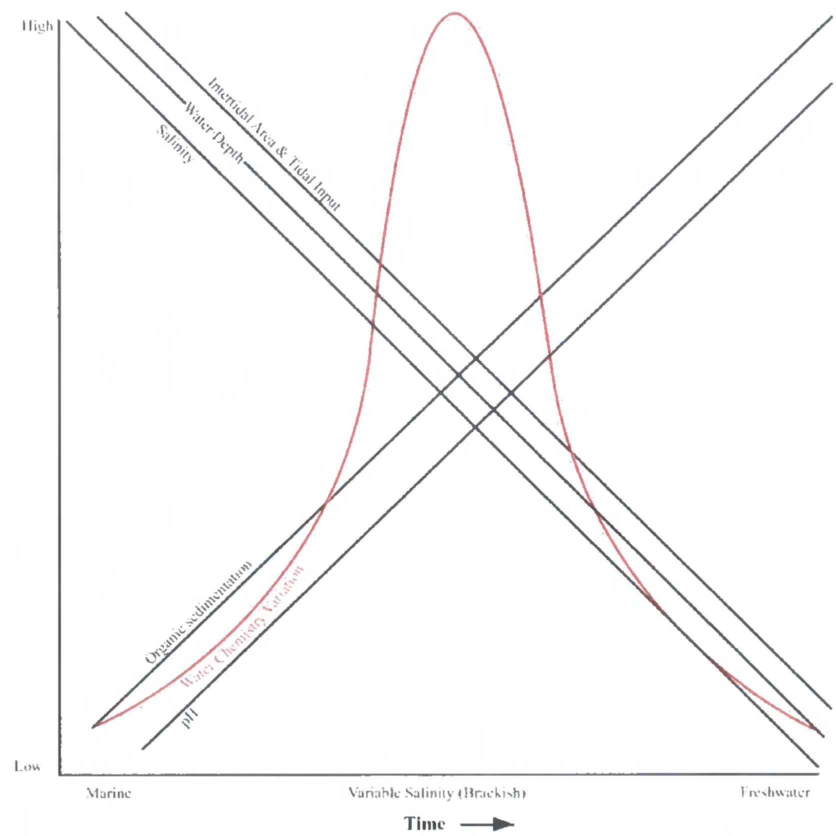


Figure 2.2: Conceptual model of the isolation process. The biological assemblage diagram in the centre shows the up-core transition from marine (nearshore shelf), through brackish (Variable salinity), to freshwater species. The column on the left indicates the typical sediment types associated with water environment The column on the right indicates the stage of the basin from Figure 2.1.

a)



b)

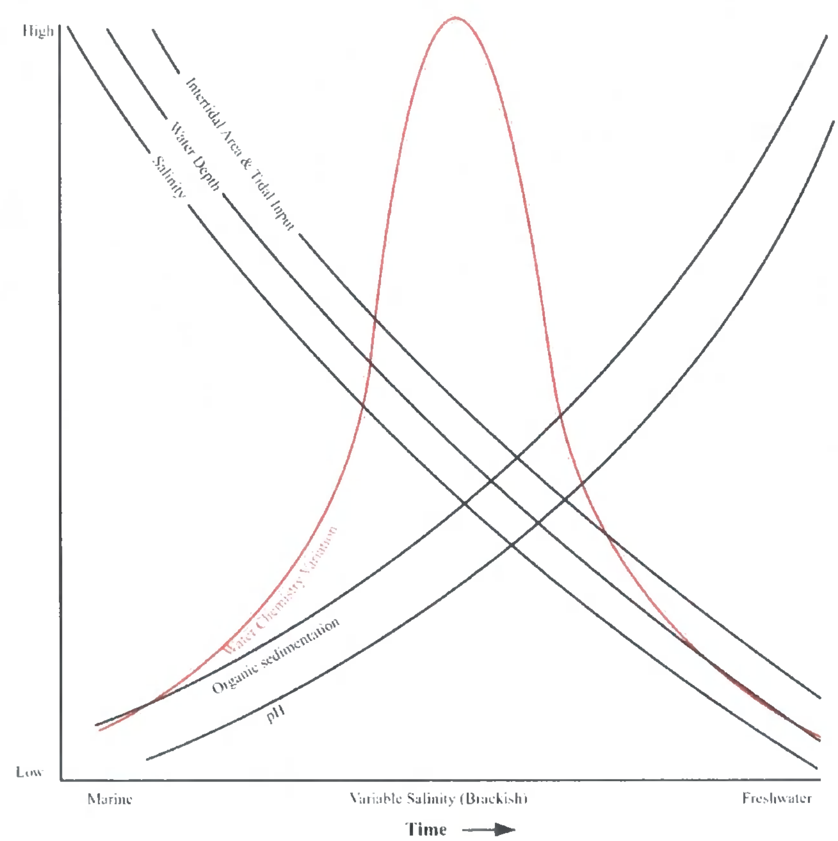


Figure 2.3: Conceptual models of the perceived changes in environmental conditions in an isolation basin, through time, during the transition from marine to freshwater conditions, assuming a) a linear change in environment and b) a curvi-linear change in environment. Both scenarios are based upon the assumption of no climate change during the process.

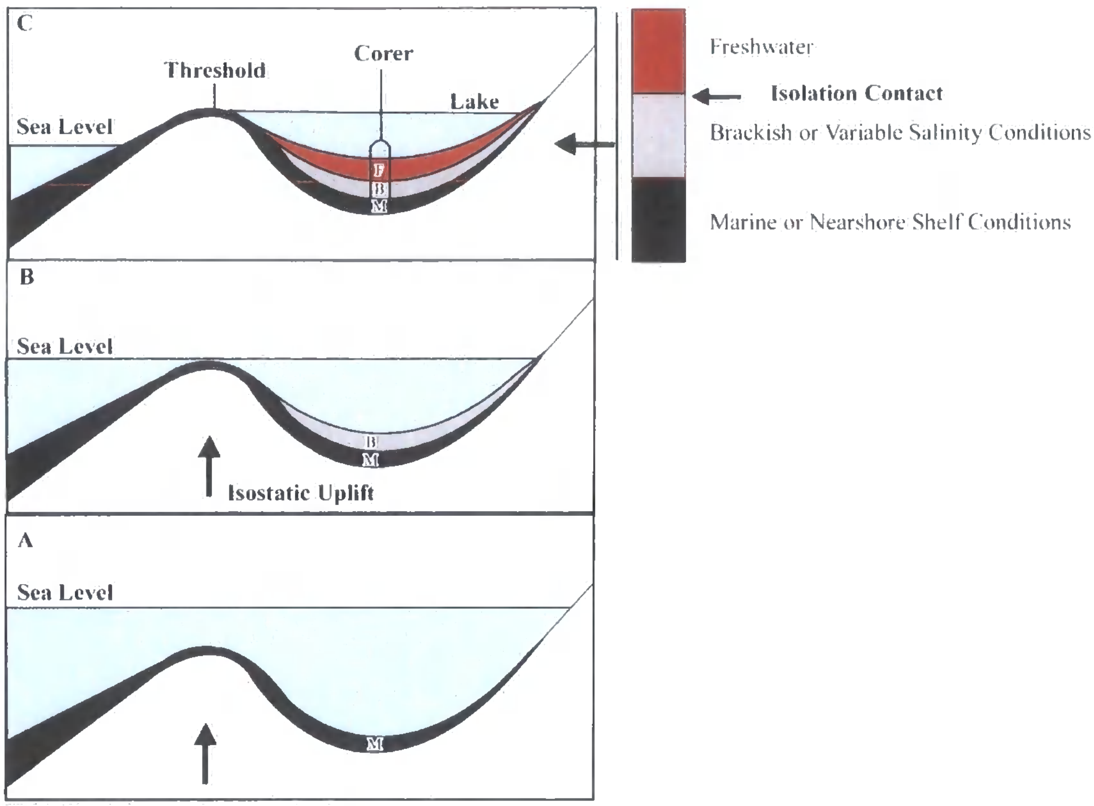


Figure 2.4: Depositional conditions in an isolation basin. A) represents the fully marine stage, B) the brackish or variable salinity stage, and C) the freshwater stage. After Hafsten (1983).

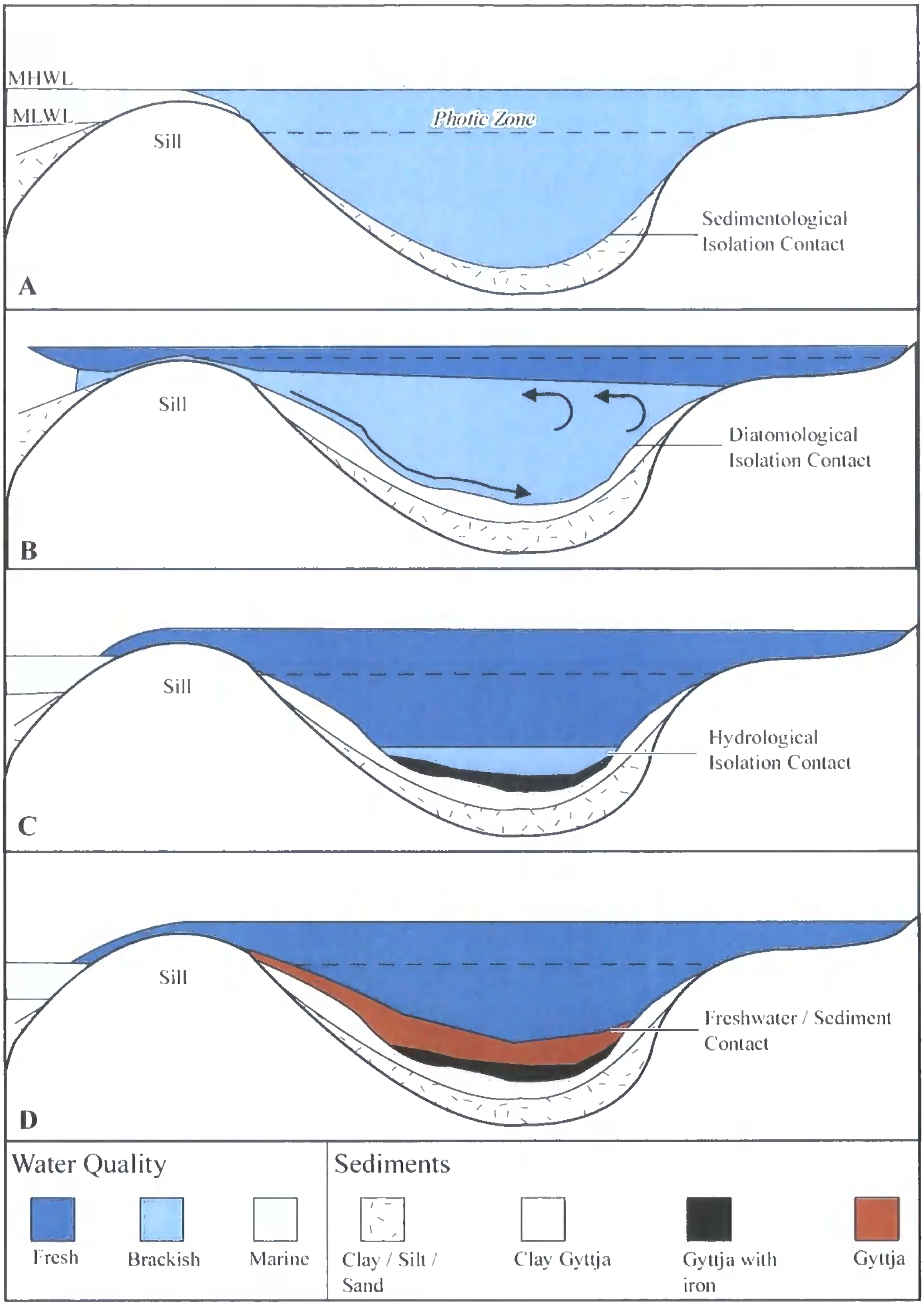


Figure 2.5: Four isolation contacts: A) Sedimentological, B) diatomological, C) hydrological, and D) the freshwater / sediment interface. The last occurs rarely, other than in deep, well-mixed basins. MHWL is Mean High Water Level, MLWL is Mean Low Water Level (after Kjemperud, 1986).

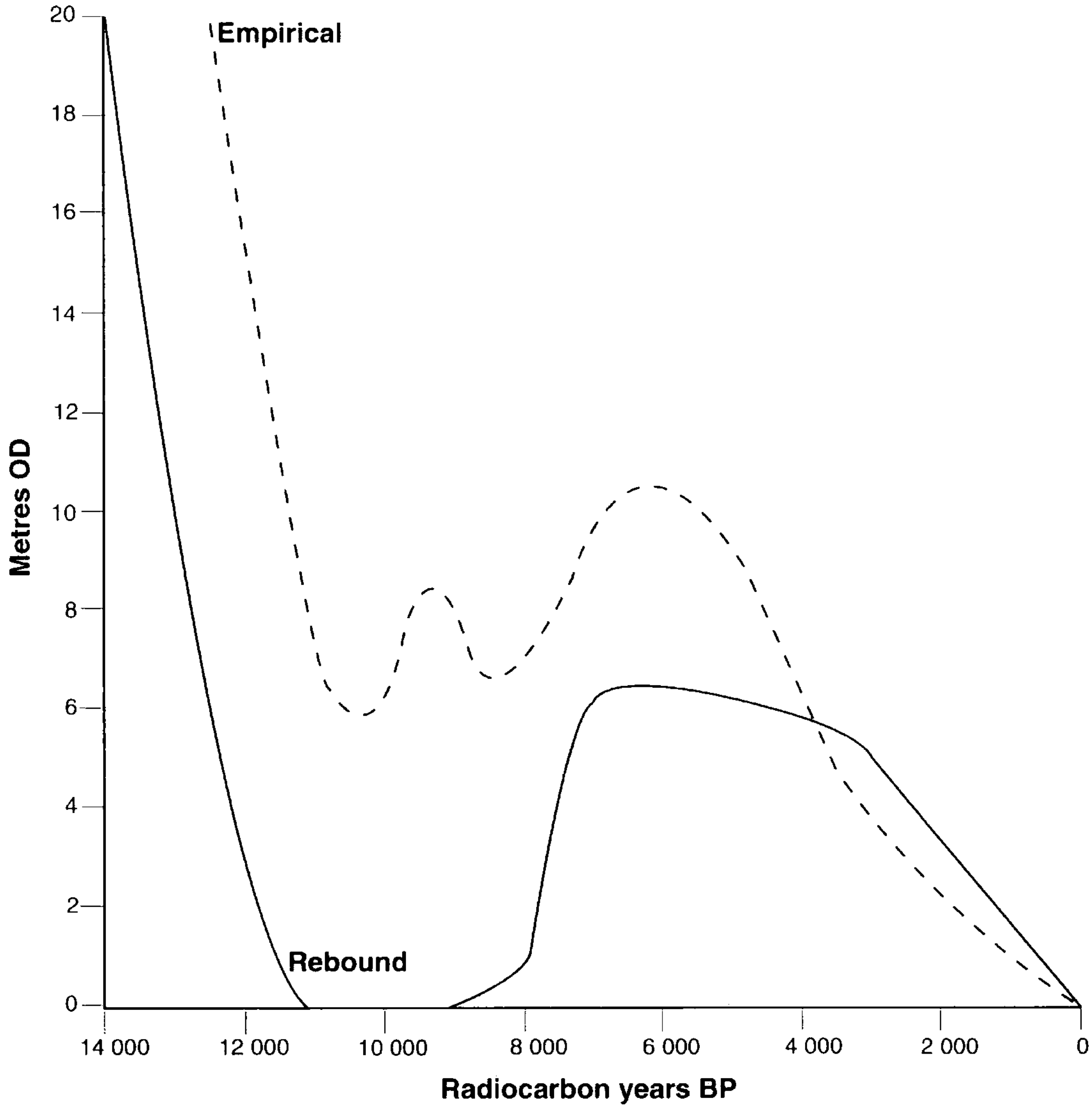


Figure 2.6: Empirical and rebound models of relative sea-level change (m OD) for northwest Scotland. The curves illustrate the significant differences between the general trends but are not intended to define precise age and altitude limits (after Shennan *et al.*, 1995).

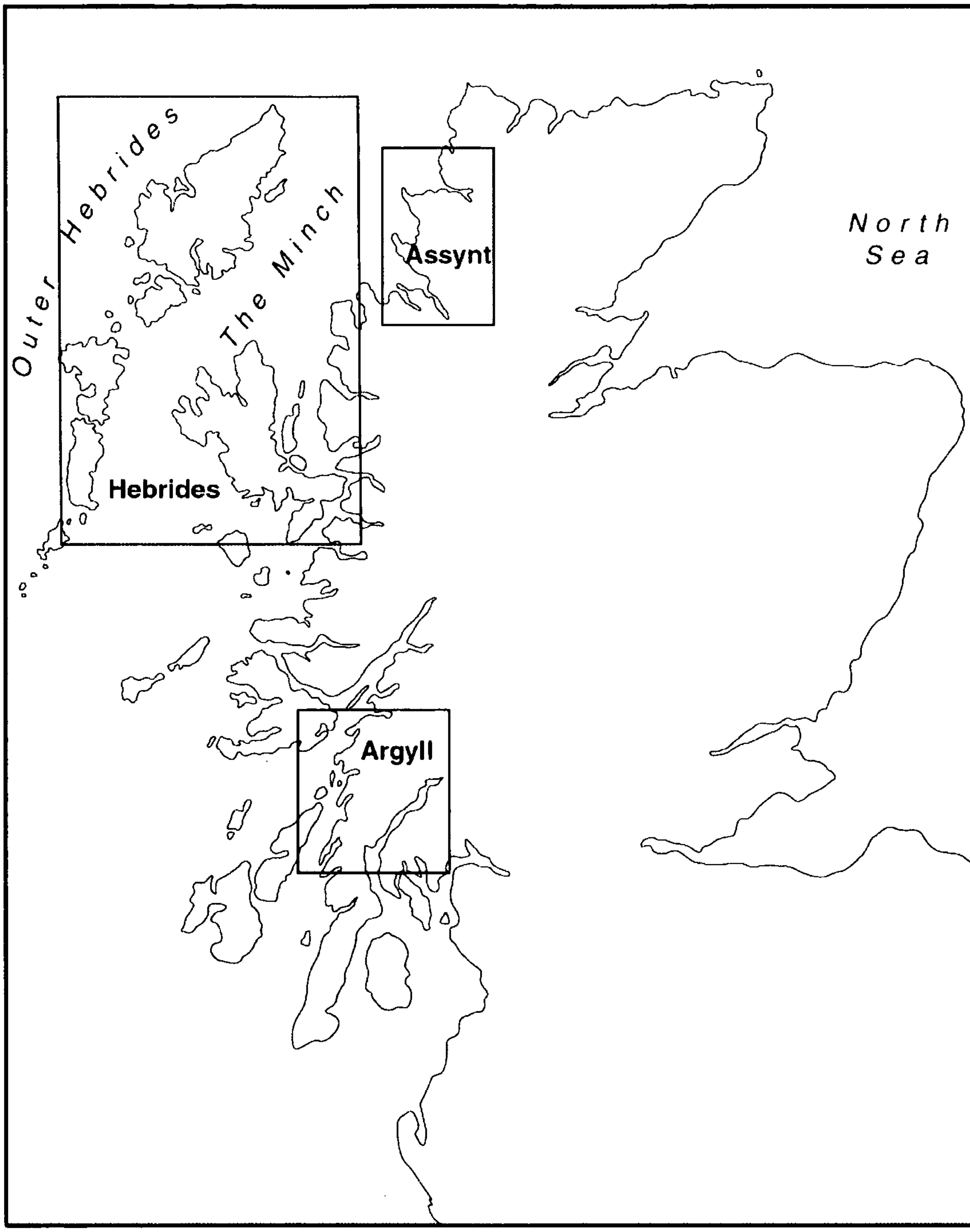


Figure 3.1.1: Location map of Scotland, showing the three main field areas.

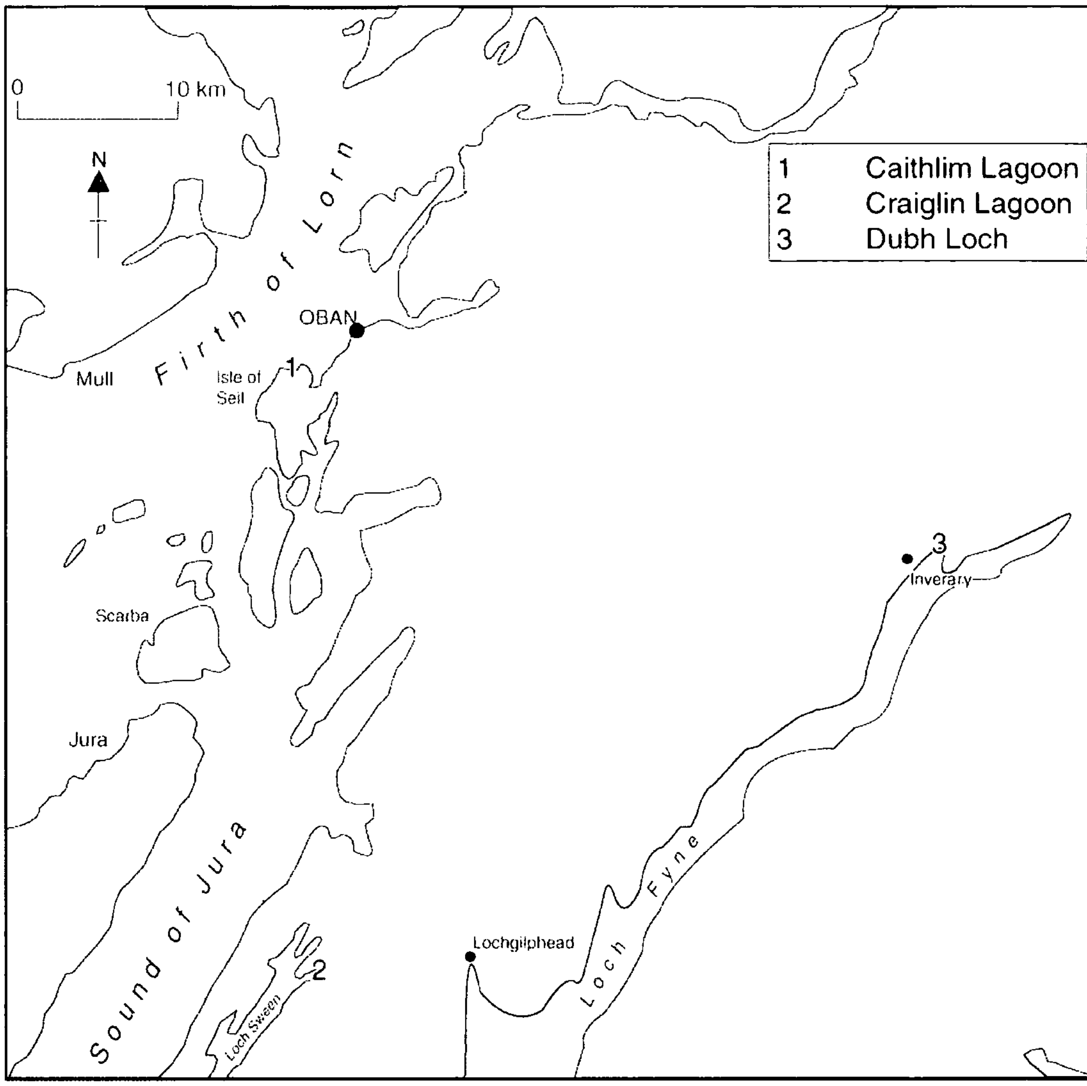


Figure 3.1.2: Location map of Argyll, showing the three field sites in this area.

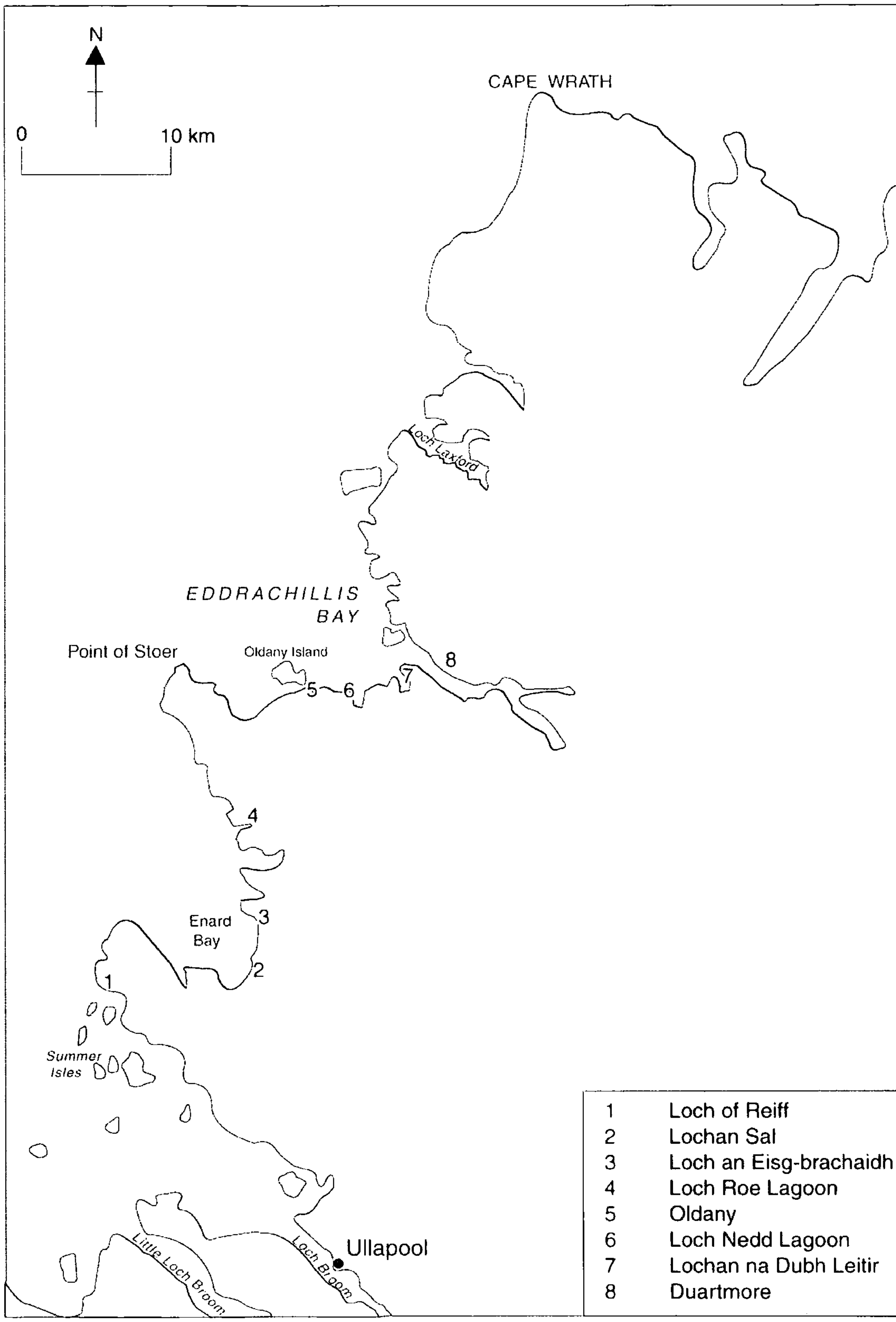


Figure 3.1.3: Location map of Assynt, showing the eight field sites in this area.

Figure 3.1.4: Location map of the Outer and Inner Hebrides, showing the nine field sites in this area.

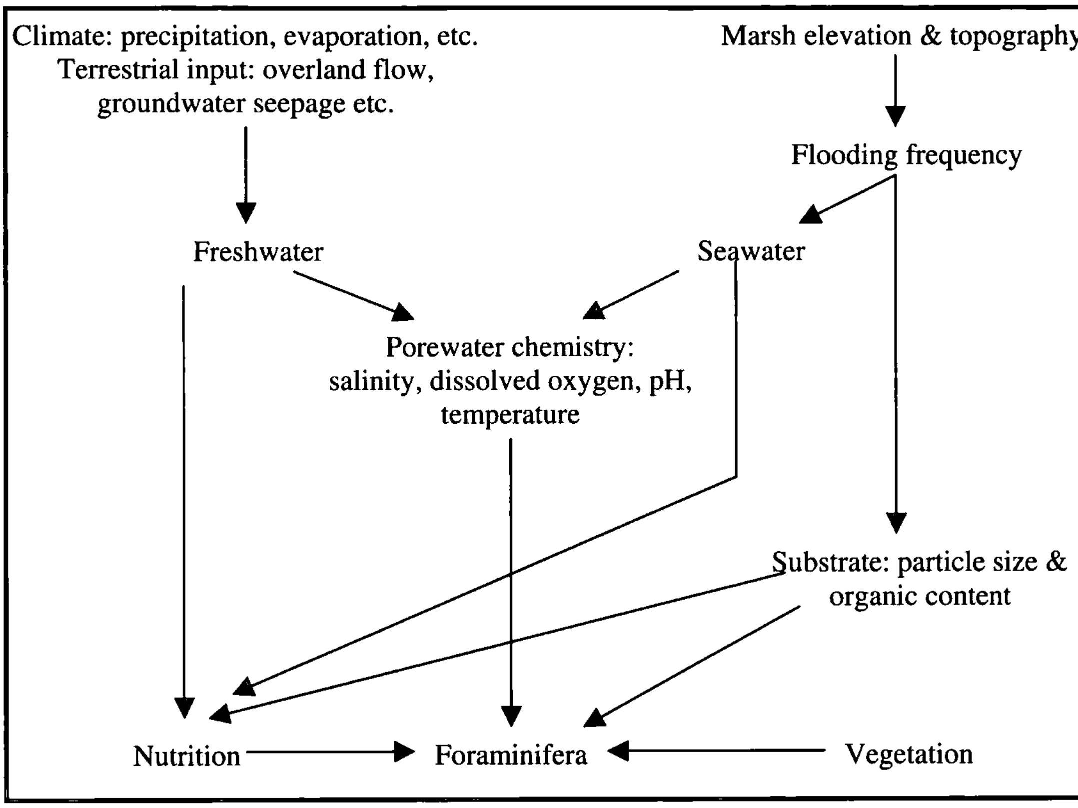


Figure 3.2: The proposed relationship between foraminifera and environmental variables on saltmarshes (after de Rijk, 1995; Horton, 1997). As there is no published work for shallow sub-tidal foraminiferal ecology, saltmarsh is used as an example, on the assumption that it is the most similar habitat with available published data.

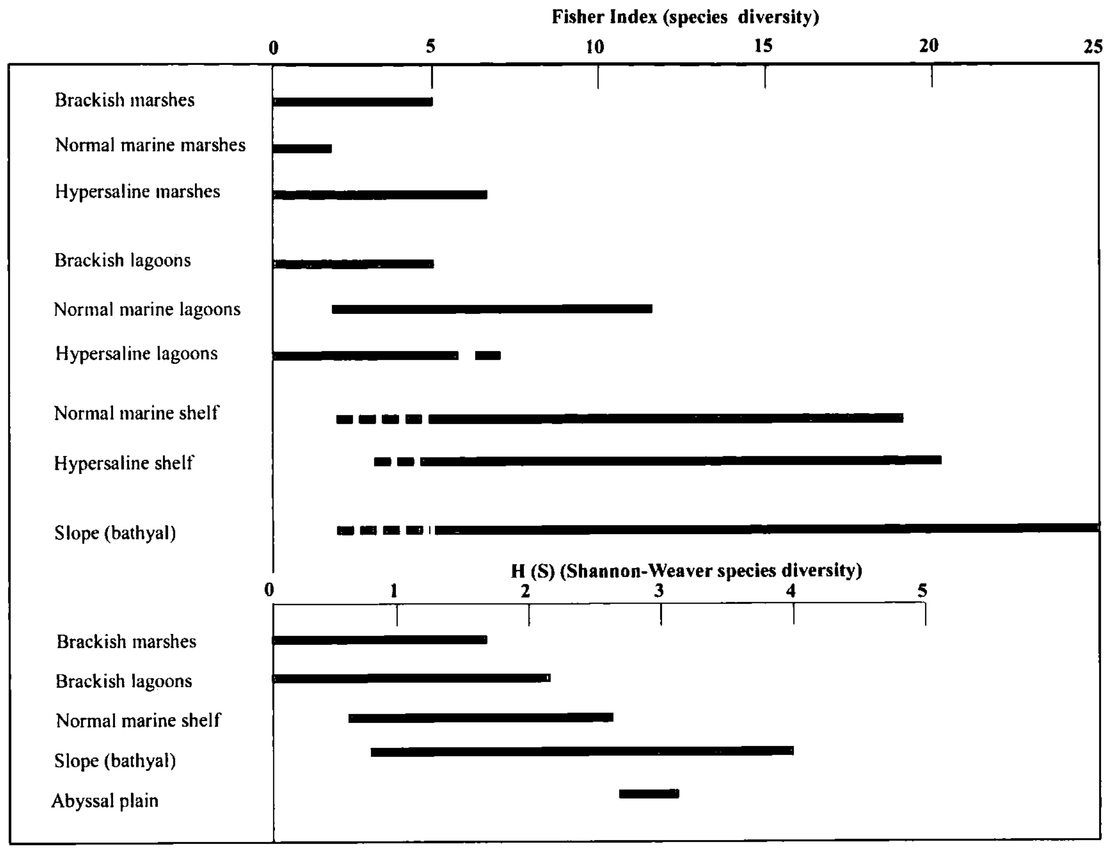


Figure 3.3: Summary of diversity data for living foraminiferal assemblages, where the Fisher (α) and Shannon-Weaver (H(S)) indices indicate the degree of species diversity. The main area of interest is that of the brackish, marine and hypersaline lagoons (Source: Murray, 1991).

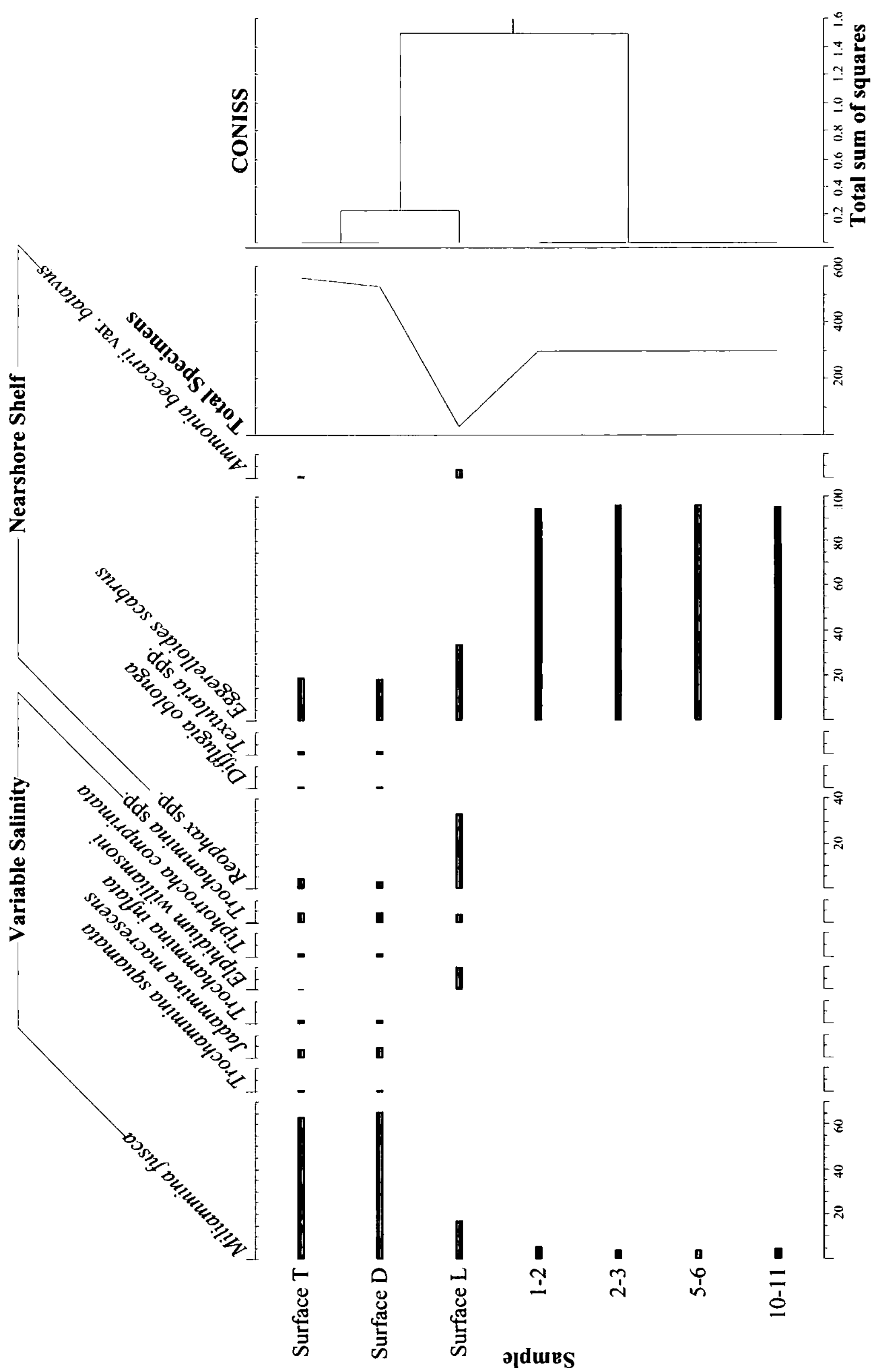


Figure 3.4.1: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, at Locheport 1, Isle of North Uist, Outer Hebrides.

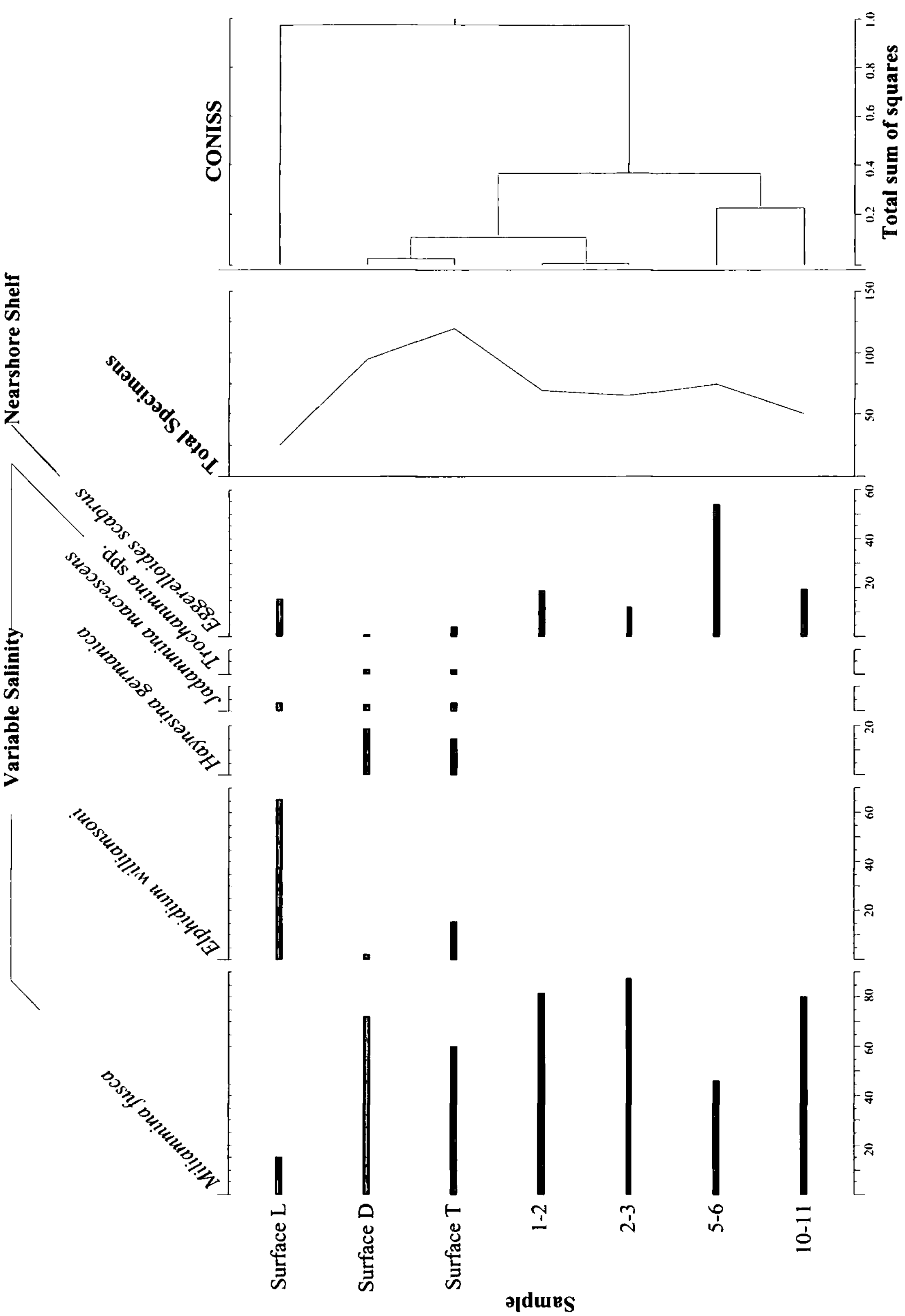


Figure 3.4.2: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, taken from a basin in Locheport, Isle of North Uist, Outer Hebrides.

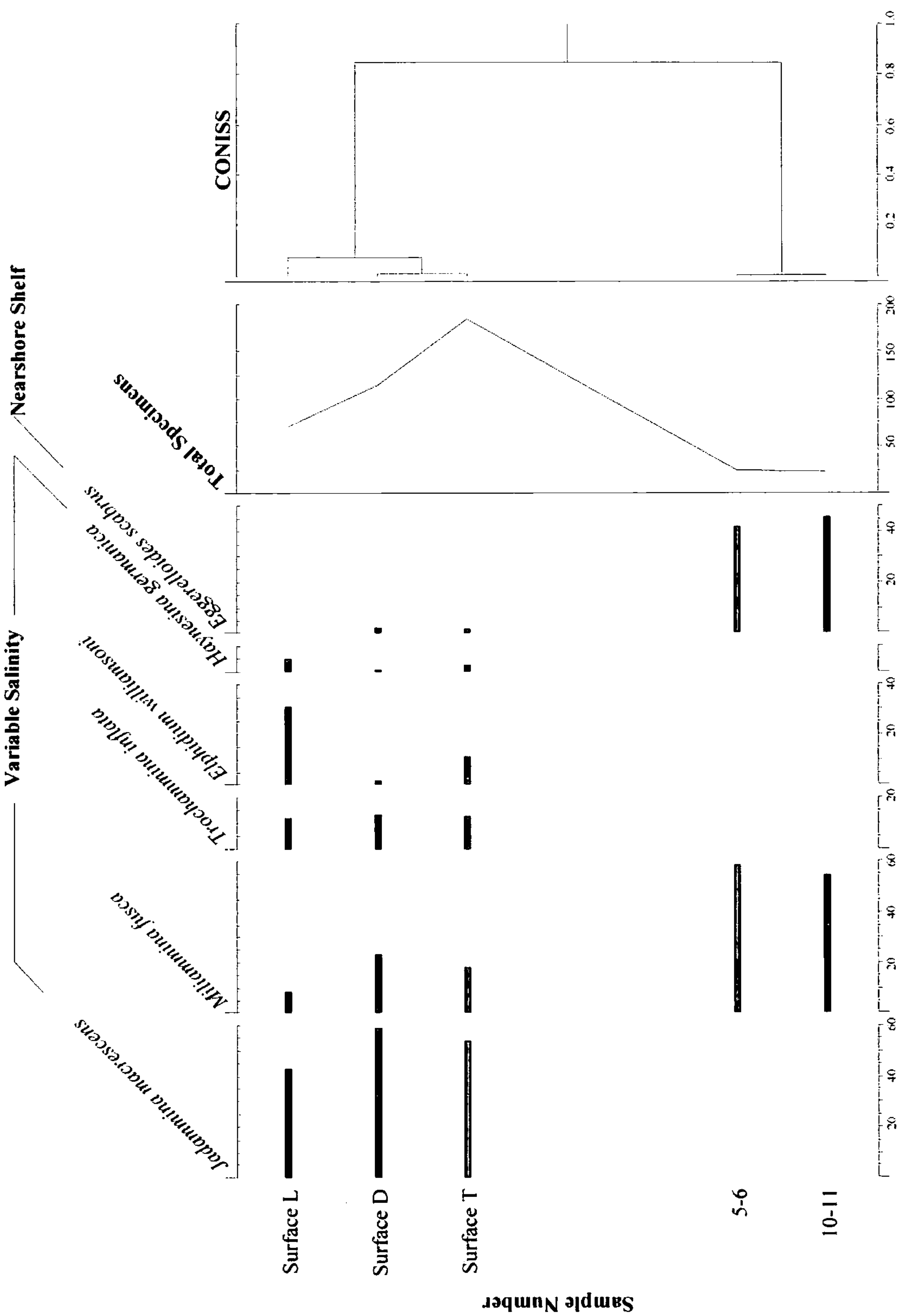


Figure 3.4.3: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, taken from a basin on the Isle of North Uist, Outer Hebrides.

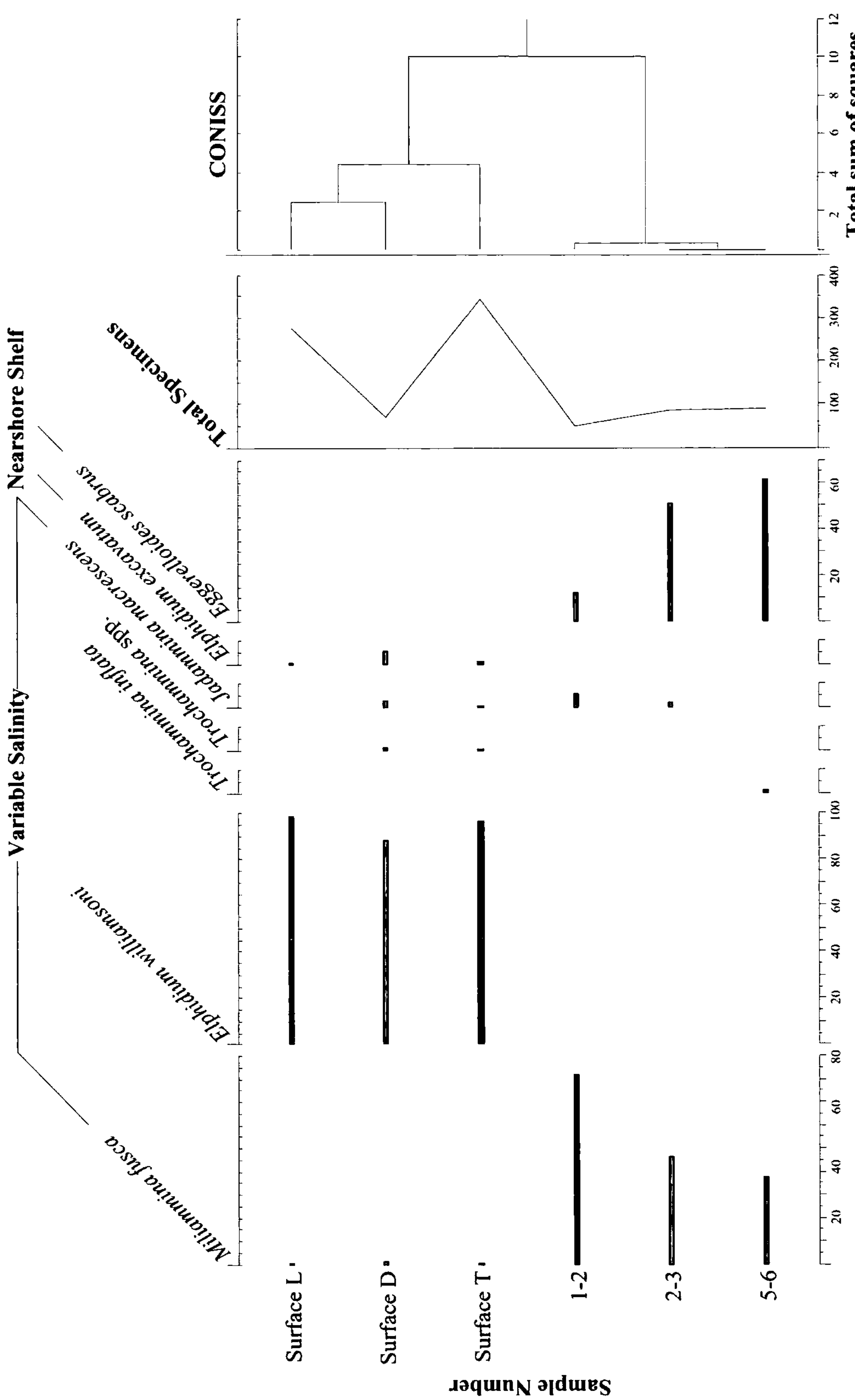


Figure 3.4.4: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, taken from a basin on the Isle of North Uist, Outer Hebrides.

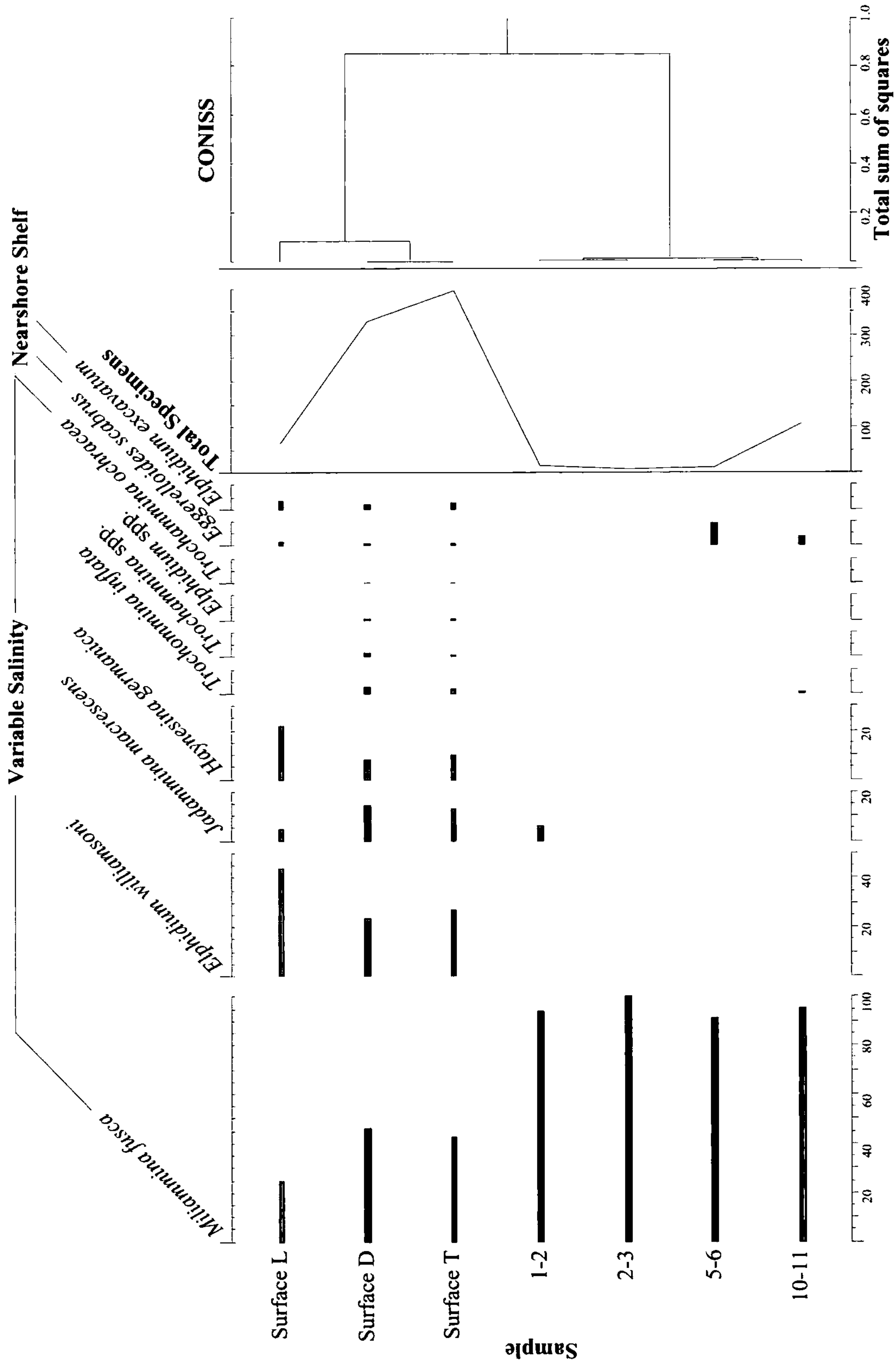


Figure 3.4.5: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, taken from a basin on the Isle of North Uist.

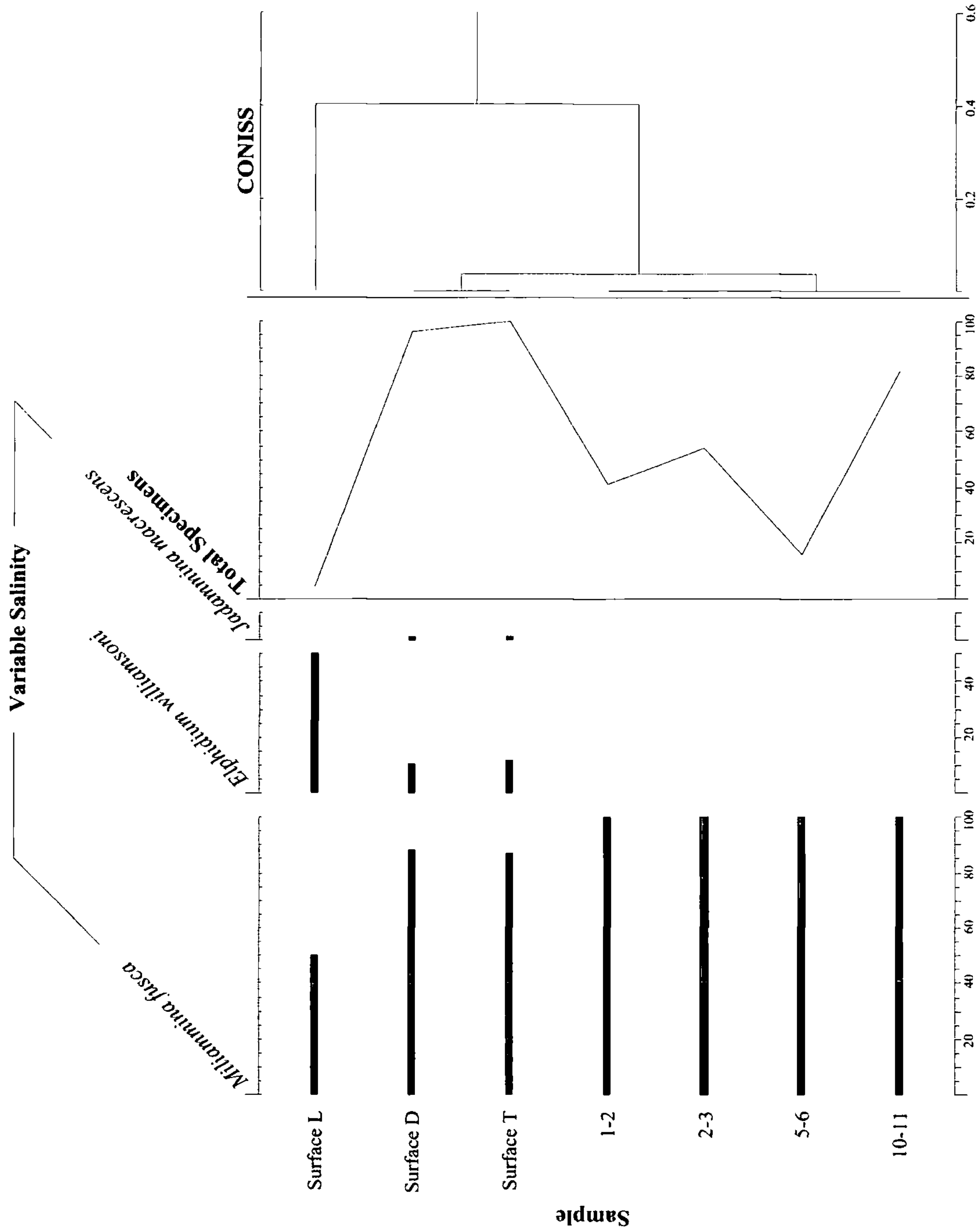


Figure 3.4.6: Modern surface assemblages (life, death and total (life + death)), compared to fossil data from a short core, taken from a basin in the Loch Carnan area, Isle of South Uist, Outer Hebrides.

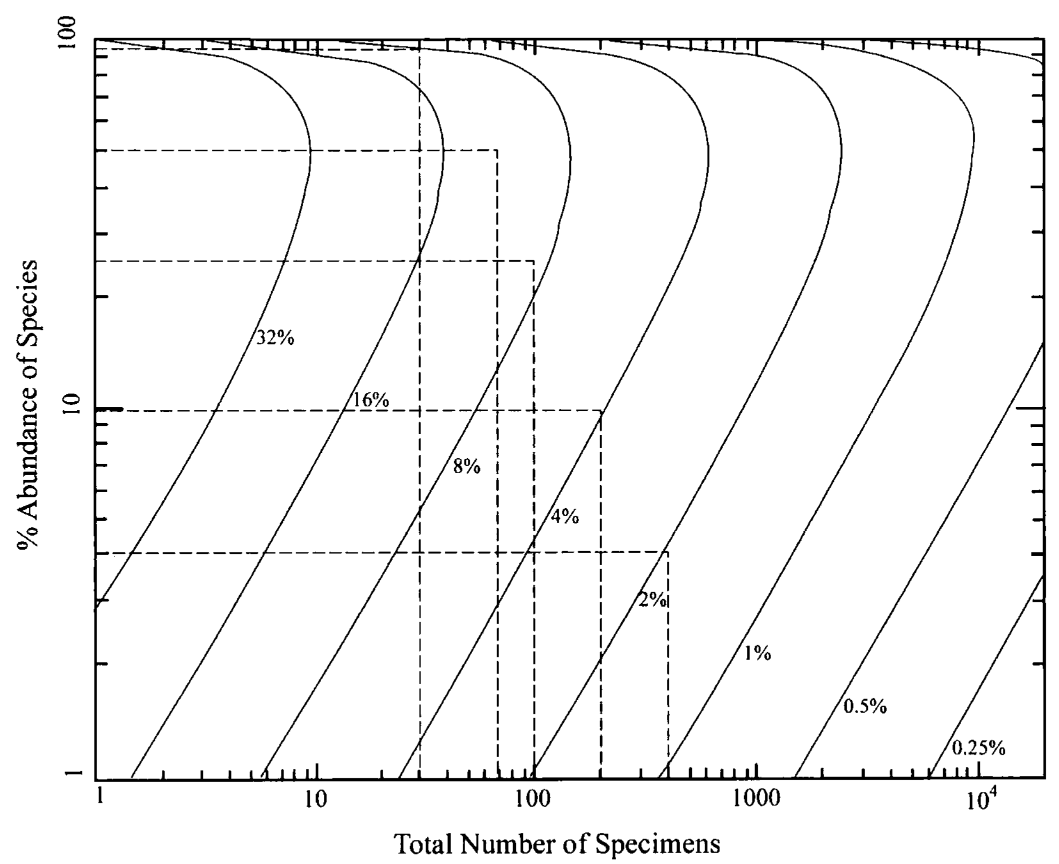


Figure 3.5: Percentage abundance versus total number of species, plotted logarithmically. The contours are errors at ± 'x' % at 95% confidence level (Source: Patterson and Fishbein, 1989). Dashed lines indicate the values for total number of specimens required together with the associated error for given % abundance of species, as detailed in table 3.1.

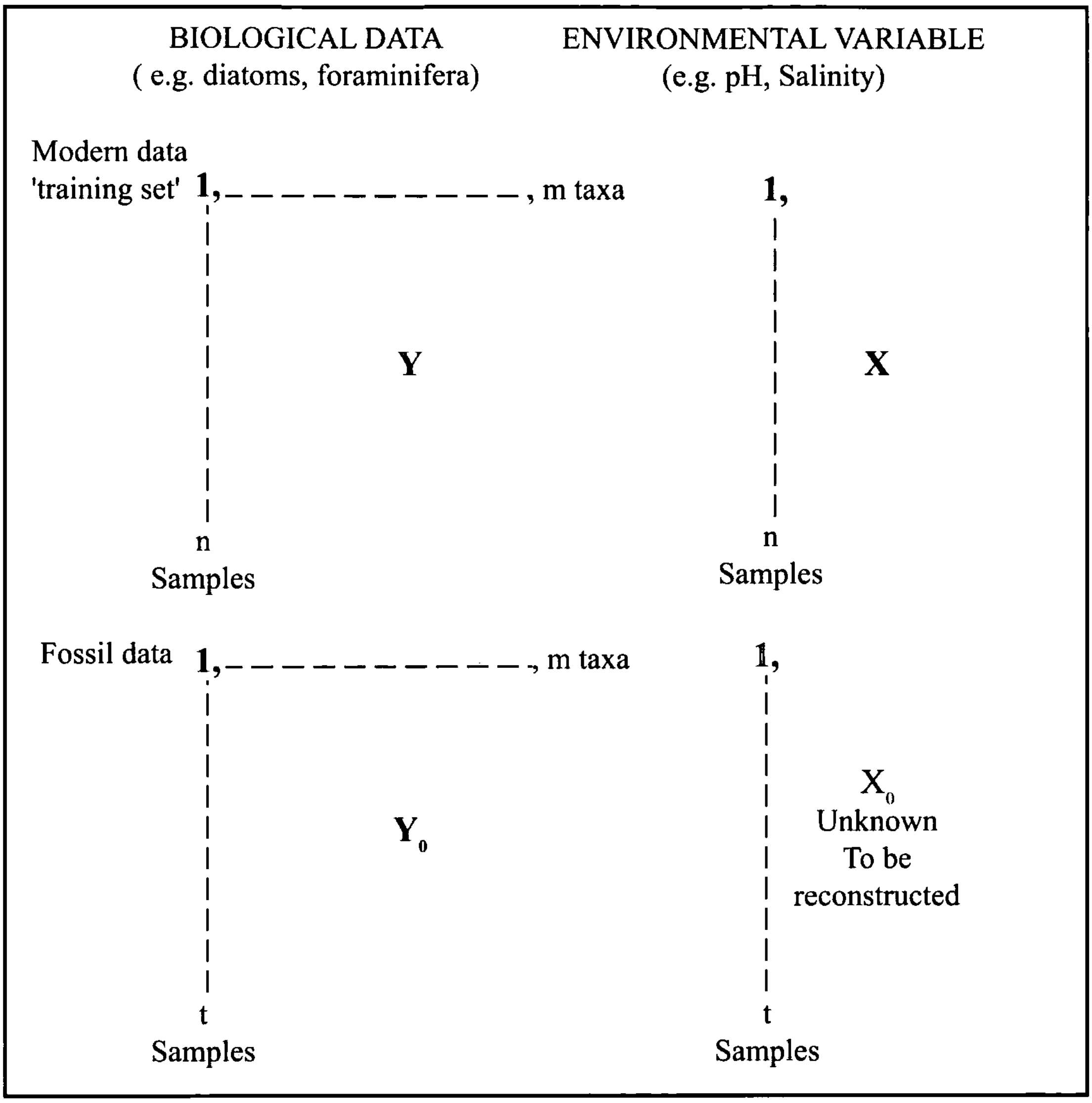


Figure 3.6: Principles of quantitative environmental reconstruction showing X_0, the unknown environmental variable to be reconstructed from fossil assemblage Y_0 consisting of *m* taxa in *t* samples, and the role of a modern 'training set' consisting of modern biological data *Y* of *m* taxa at *n* sites and environmental data *X* for the same *n* sites (Source: Birks, 1995).

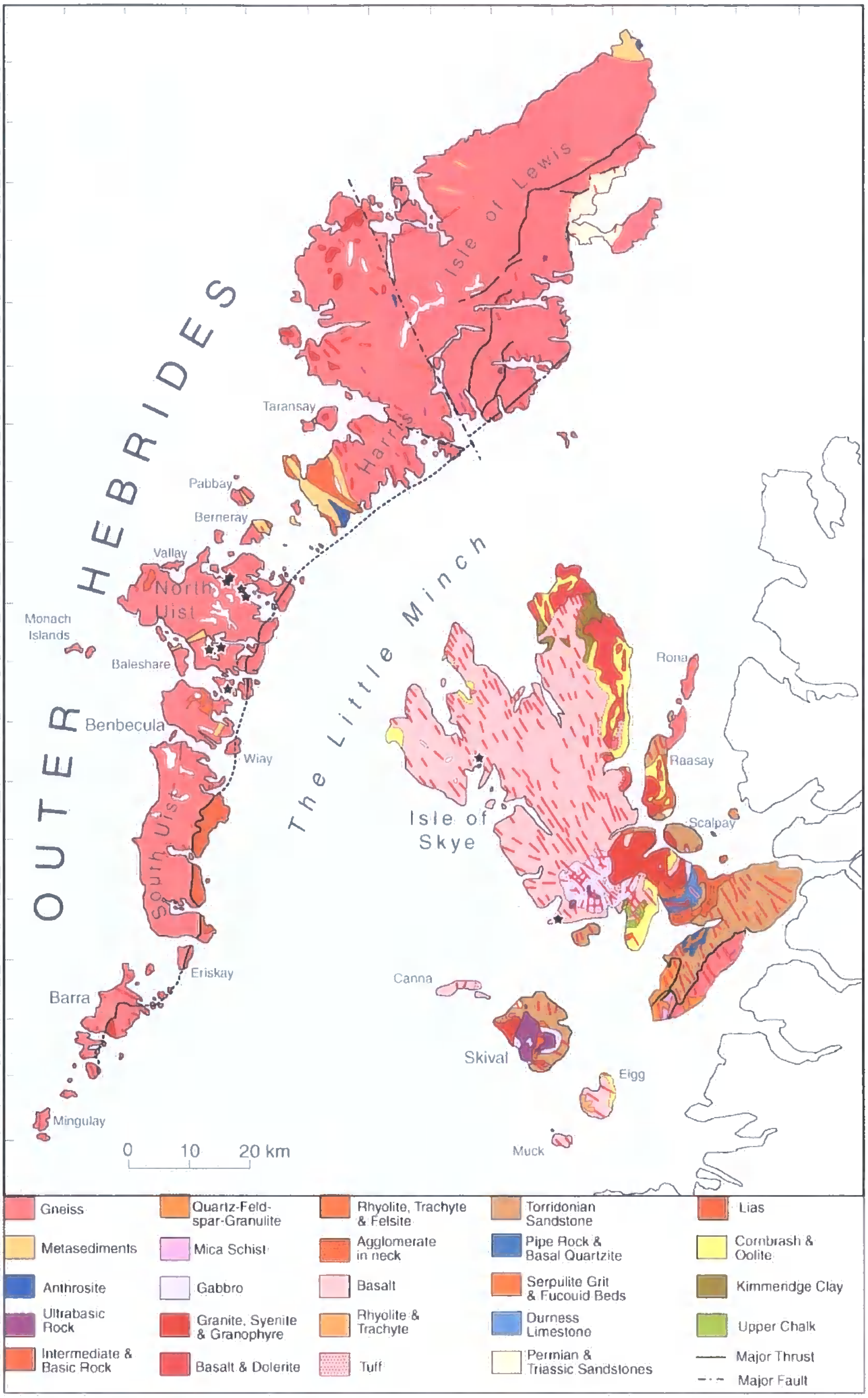


Figure 4.1: Summary geological map of the Outer Hebrides and the Isle of Skye. ★ = study site. After Ordnance Survey (1979) Geological Map of the United Kingdom North, 3rd Edition (Solid).

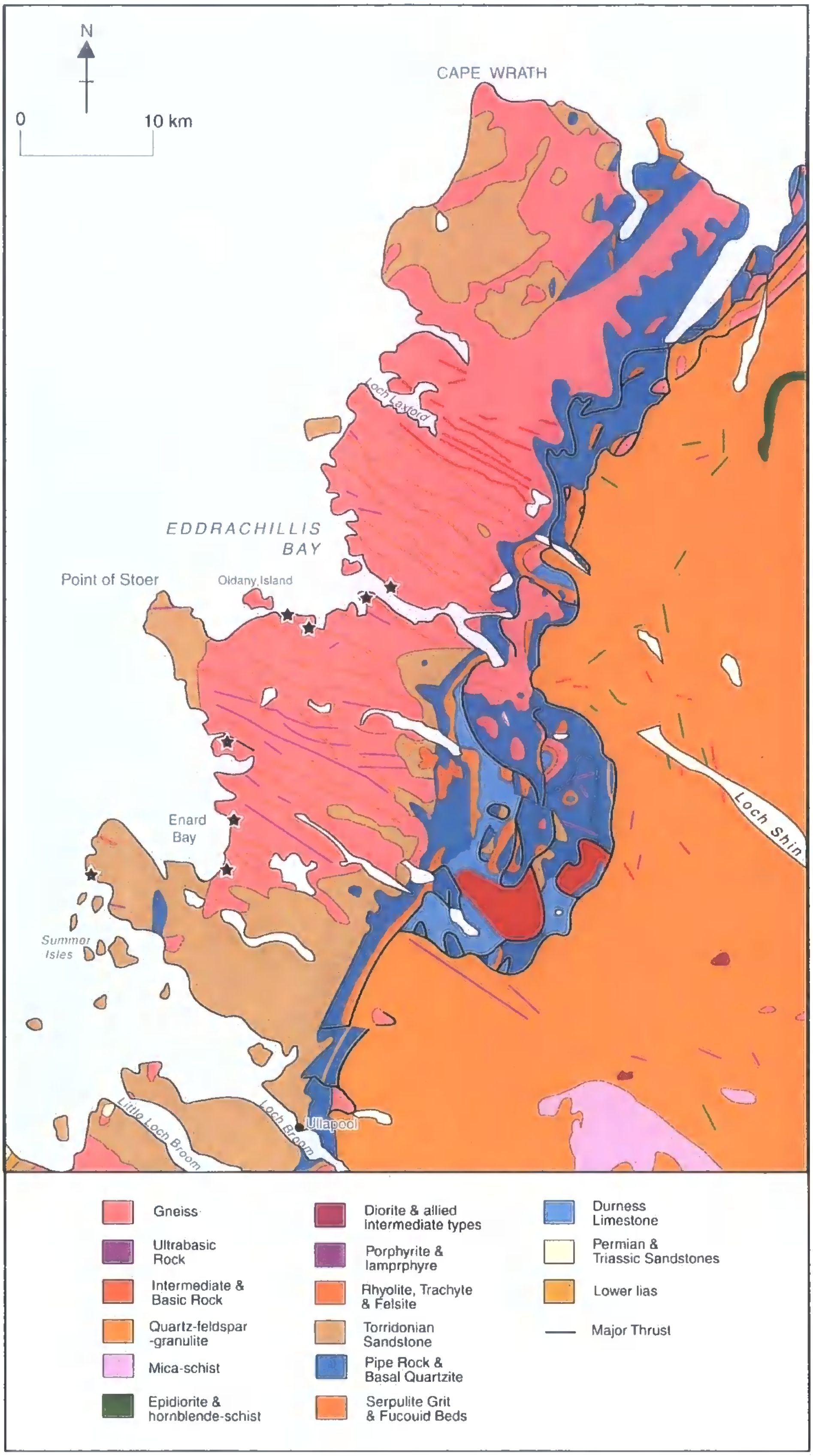


Figure 4.2: Summary geological map of the Assynt area. ★ = study site. After Ordnance Survey (1979) Geological Map of the United Kingdom North, 3rd Edition (Solid).

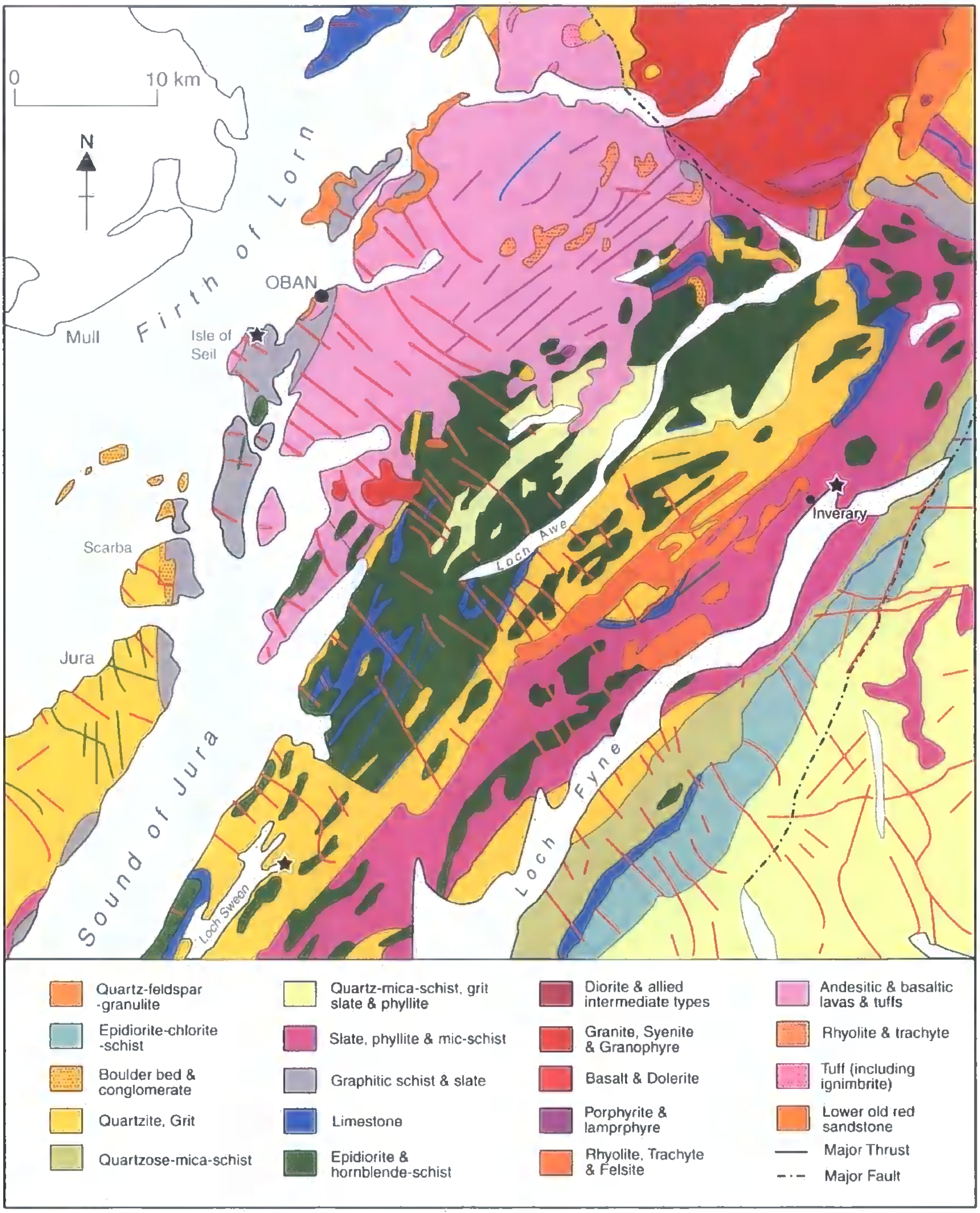


Figure 4.3: Summary geological map of Argyll. ★ = study site. After Ordnance Survey (1979) Geological Map of the United Kingdom North, 3rd Edition (Solid).

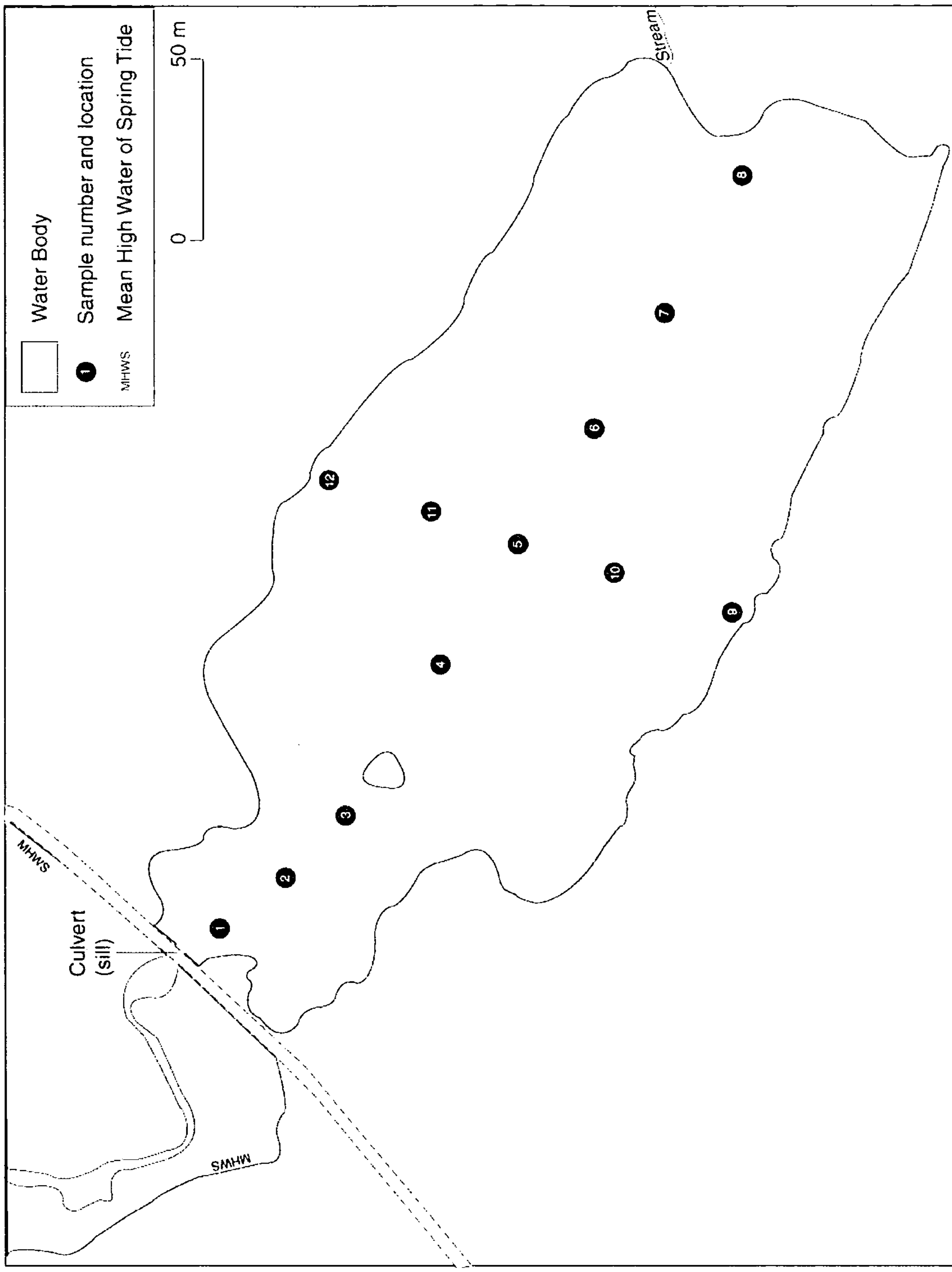


Figure 4.4.1: Oban Trumisgarry, Isle of North Uist.

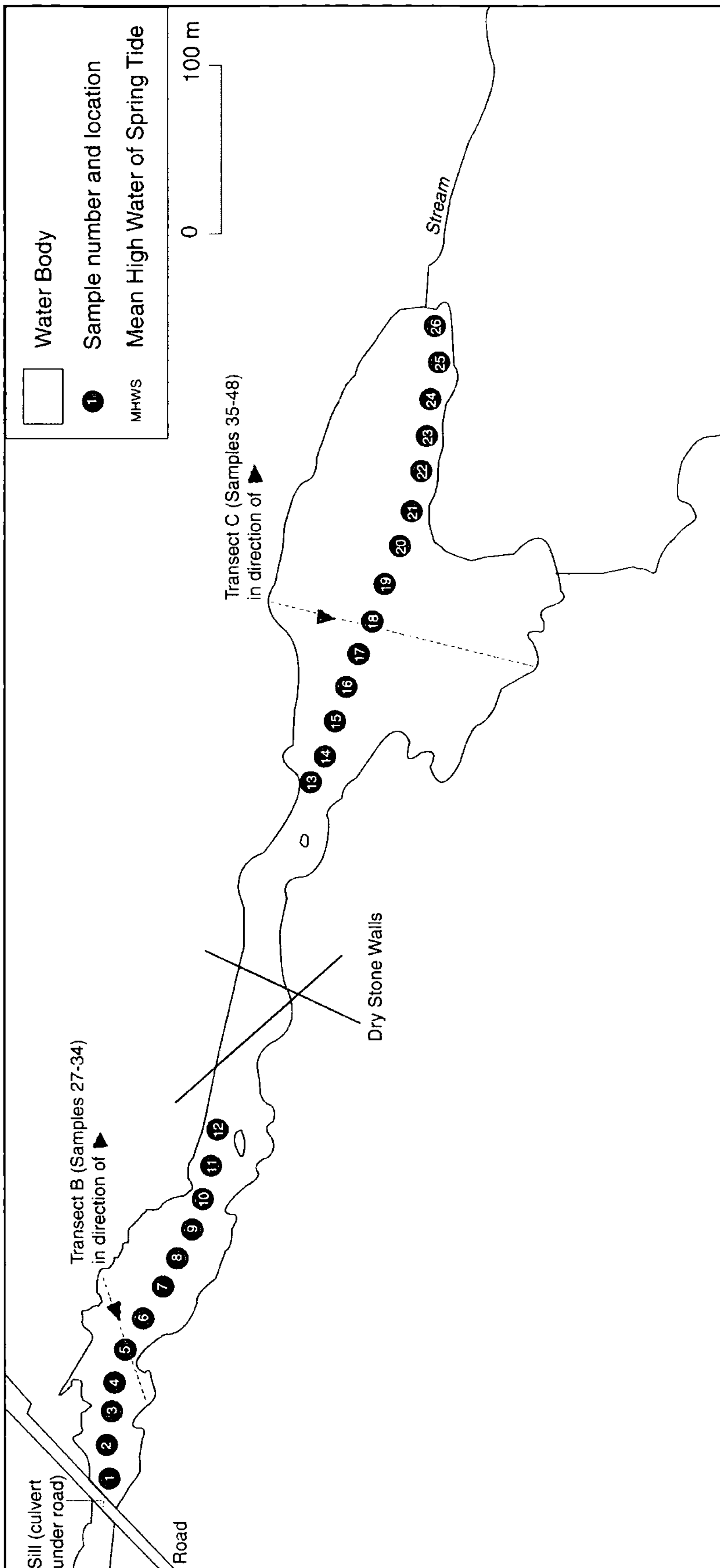


Figure 4.4.2: Oban nan Struthan, Isle of North Uist.

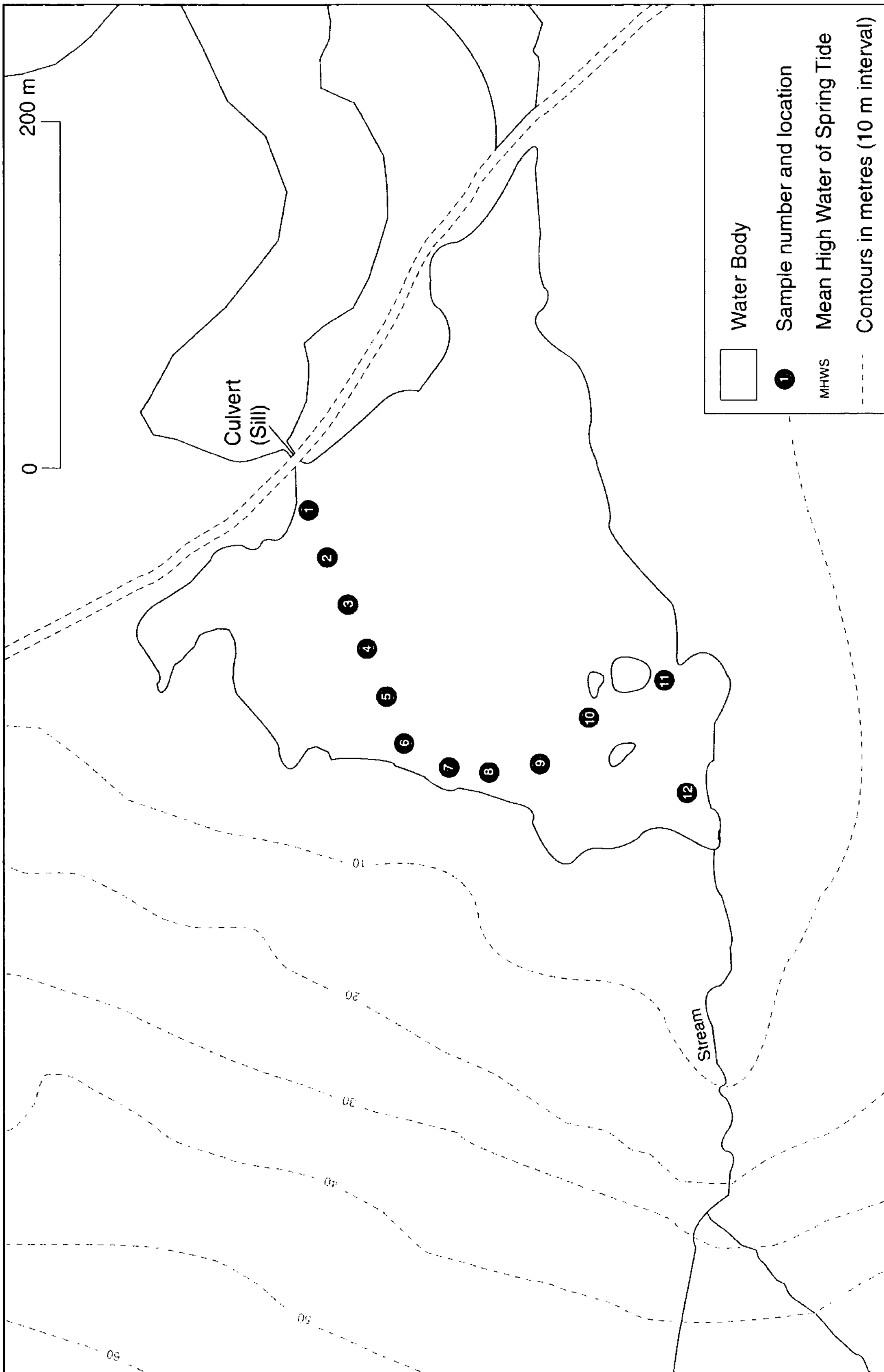


Figure 4.4.3: Alioter Lagoon, Isle of North Uist.

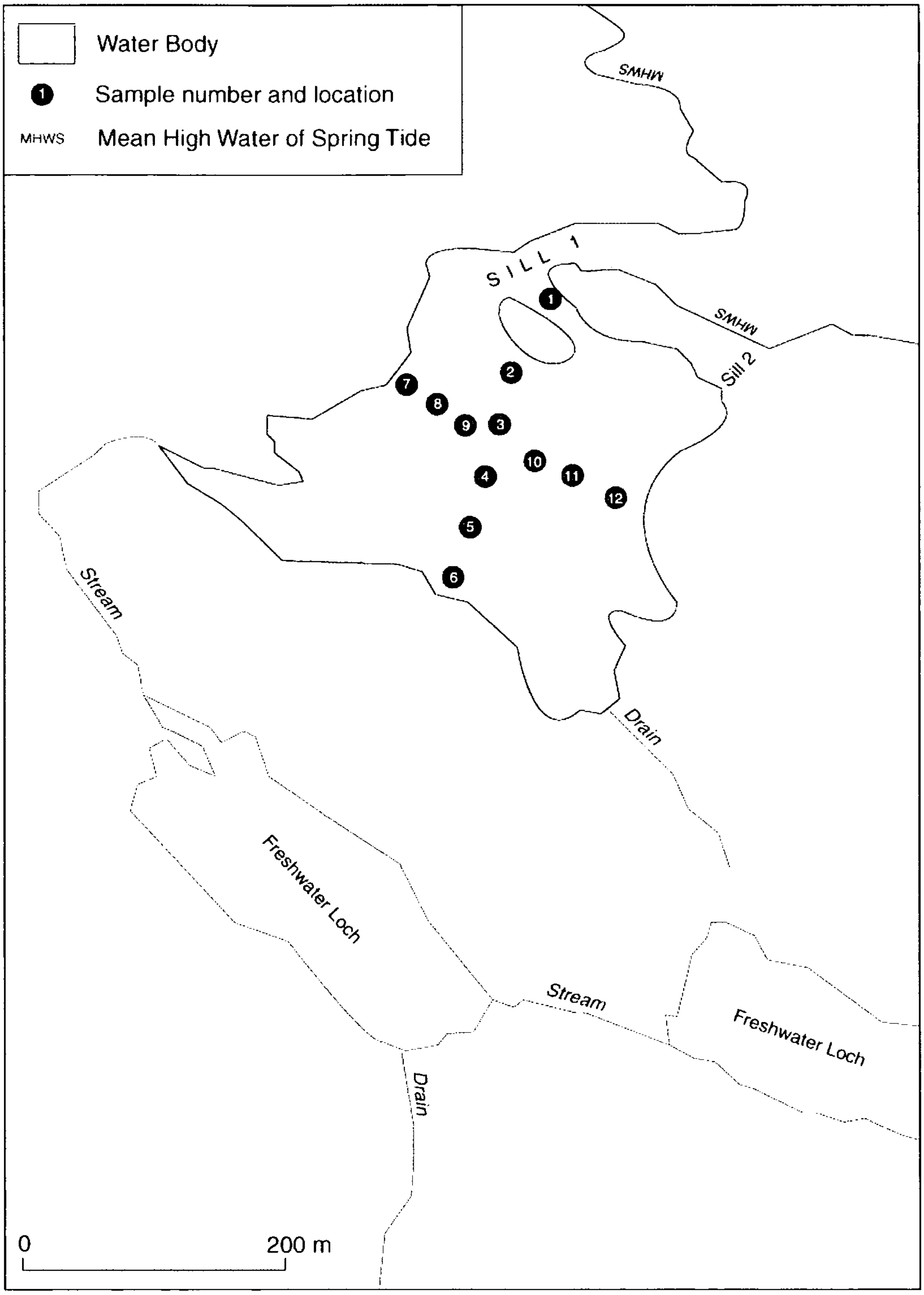


Figure 4.4.4: Bac-a-Stoc, Isle of North Uist.

Plate 4.1: Bac-a-Stoc, Isle of North Uist. The basin is in the foreground, second from the front, with the sill running out into Loch Blashaval. The basin in the immediate foreground is freshwater, and supplies a small input *via* a channel into Bac-a-Stoc.

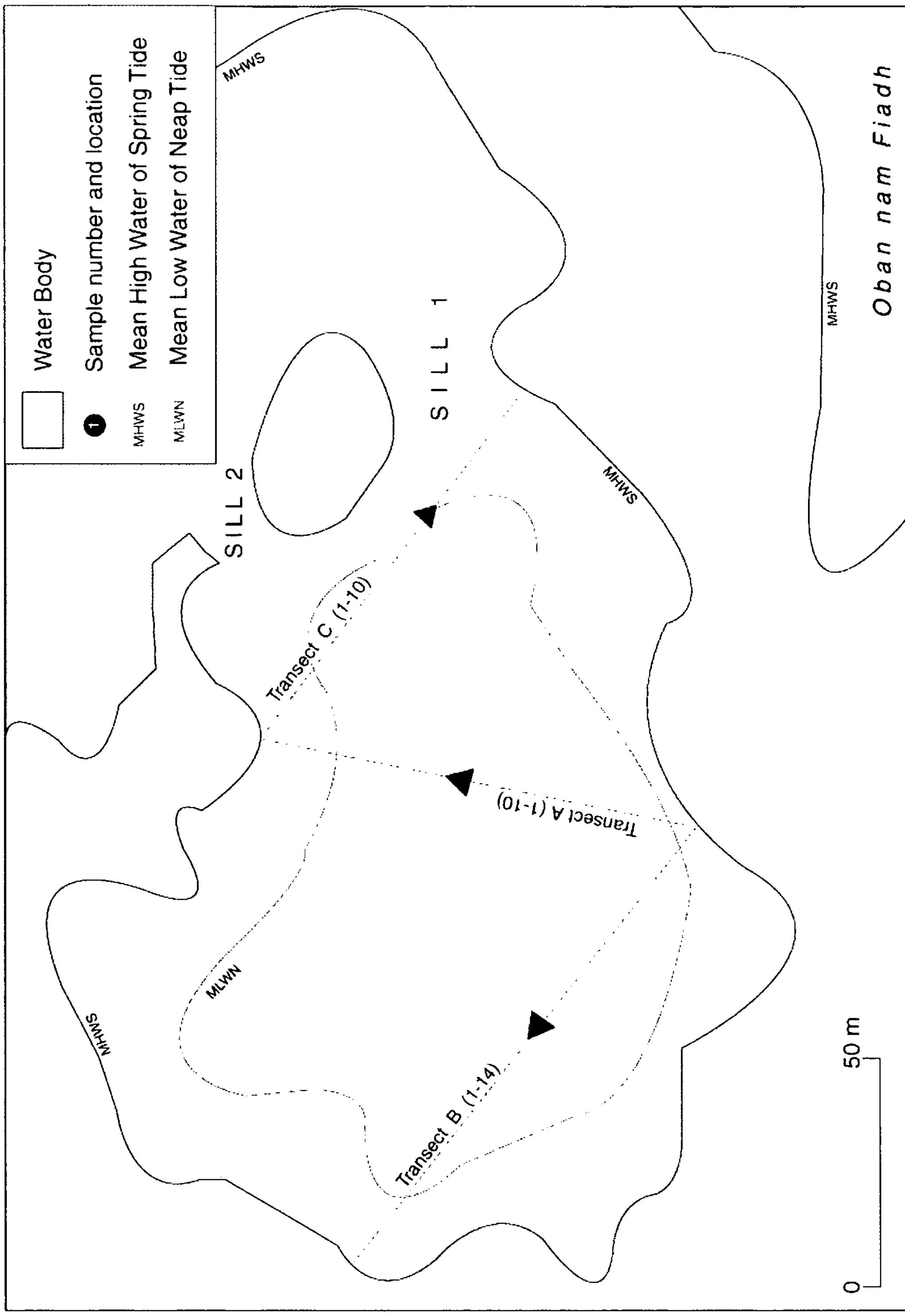


Figure 4.4.5: Locheport Basin 1, Isle of North Uist.

B)

Plate 4.2: Locheport 1 basin, Isle of North Uist. A) shows the basin and the two rock sills at low tide. B) shows the basin and both sills inundated at high water during Spring tide.

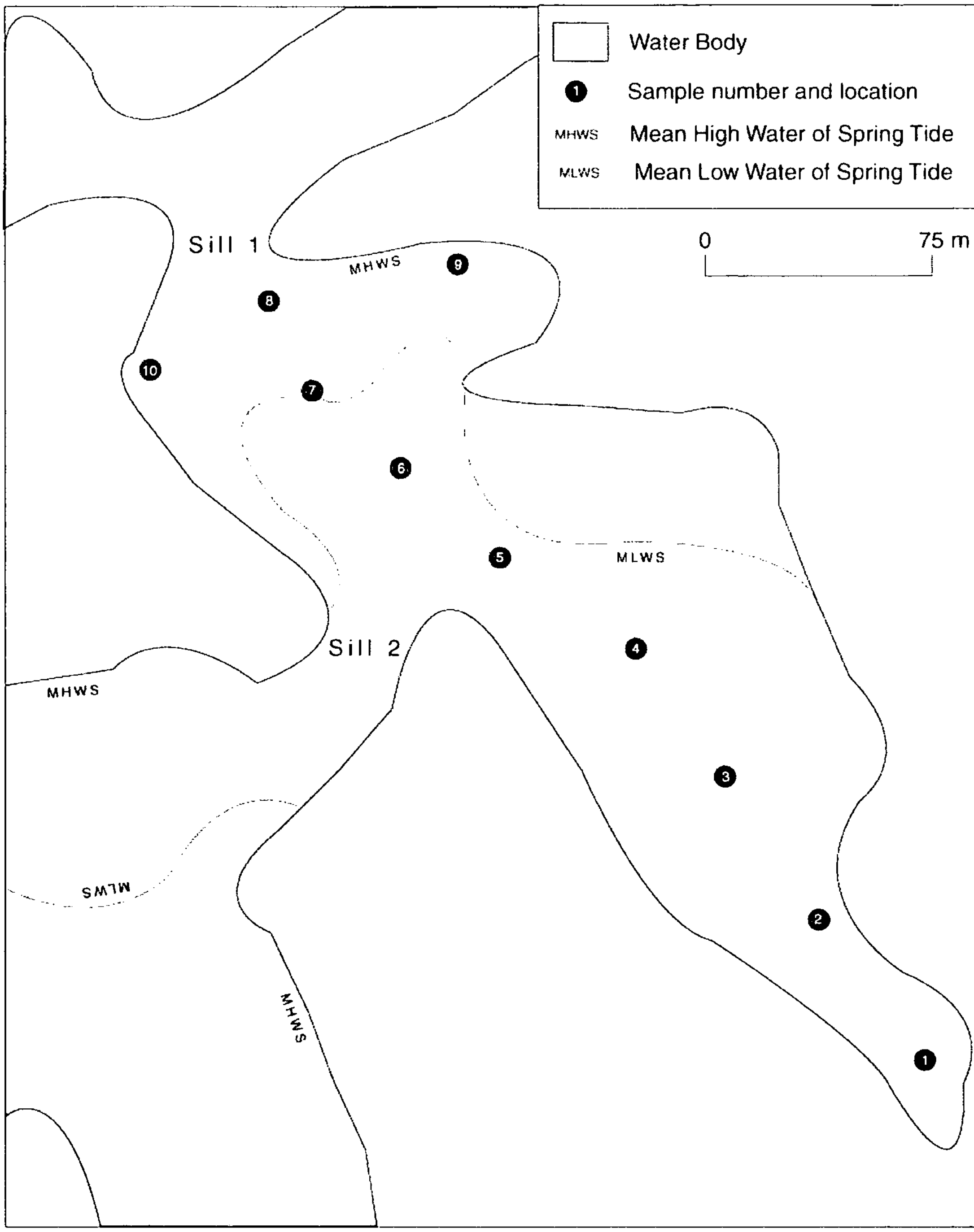


Figure 4.4.6: Locheport Basin 2, Isle of North Uist.

Plate 4.3: Tidal rapids formed over one of the sills of Locheport 2, during outflow of marine water following Spring high tide.

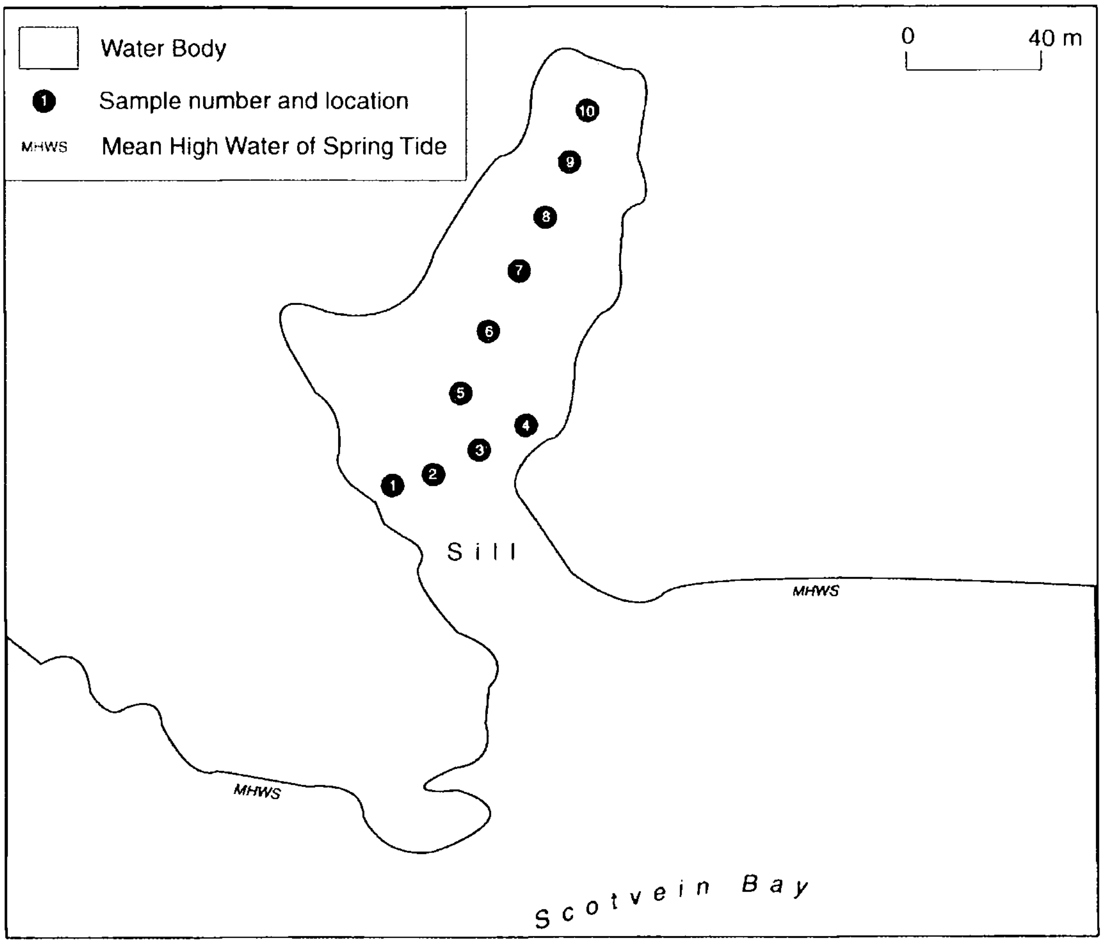


Figure 4.4.7: Grimsay, Isle of Grimsay.

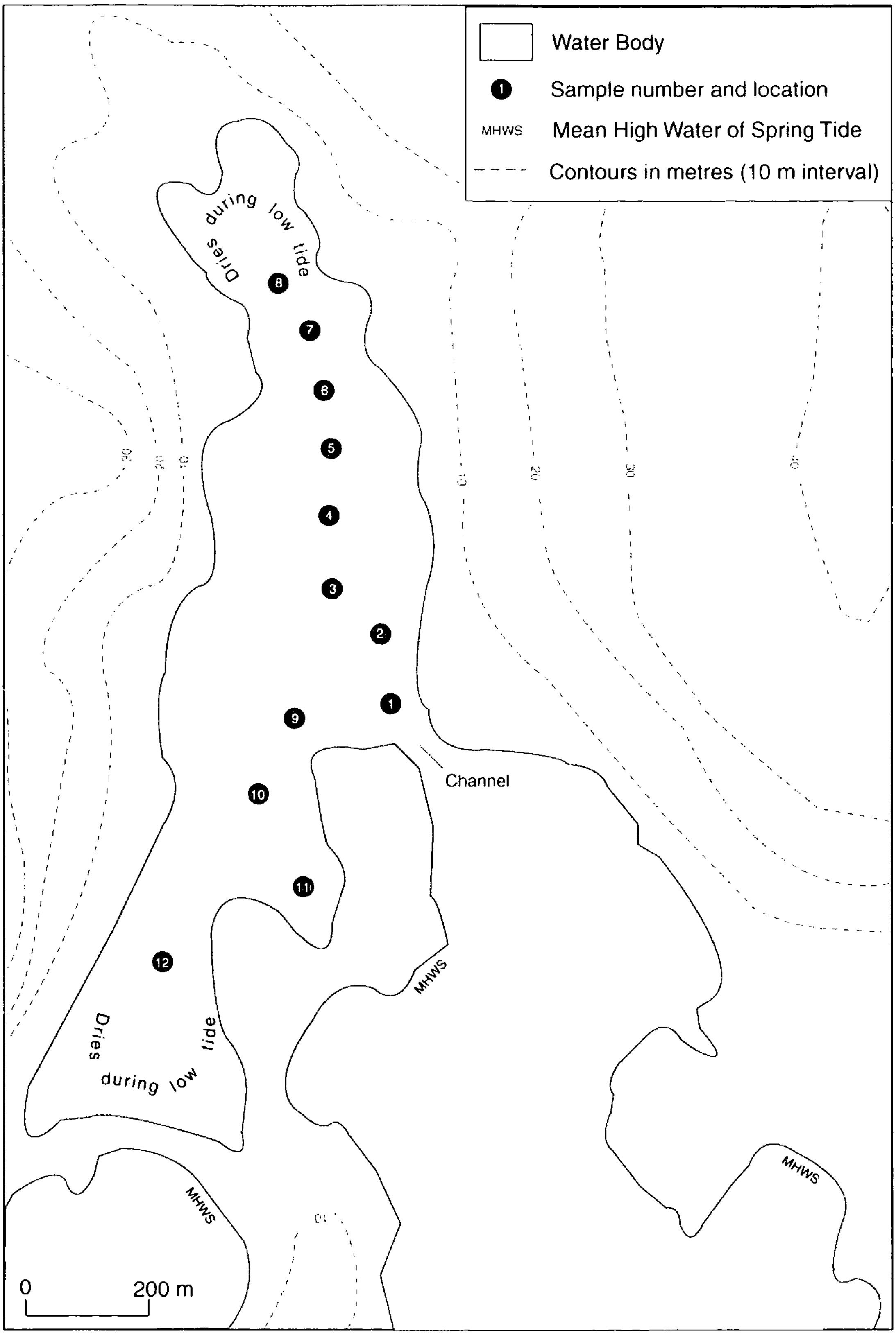


Figure 4.4.8: Pool Roag, Isle of Skye.

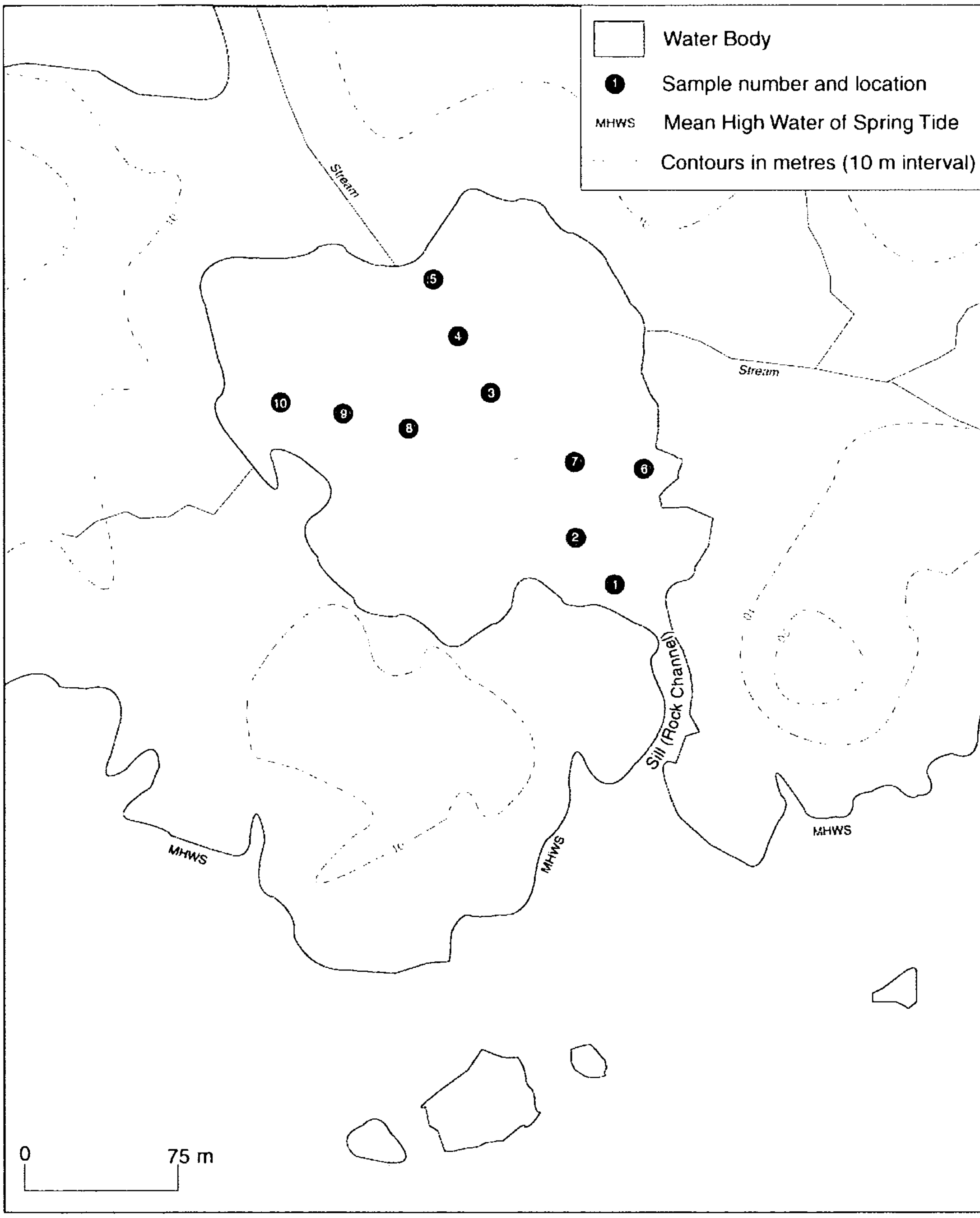


Figure 4.4.9: Loch na h'airde, Isle of Skye.

Plate 4.4: Channel linking Loch na h'airde, Isle of Skye, to the sea. The basin sill lies in the channel, in the foreground of the photograph, with the basin to the rear.

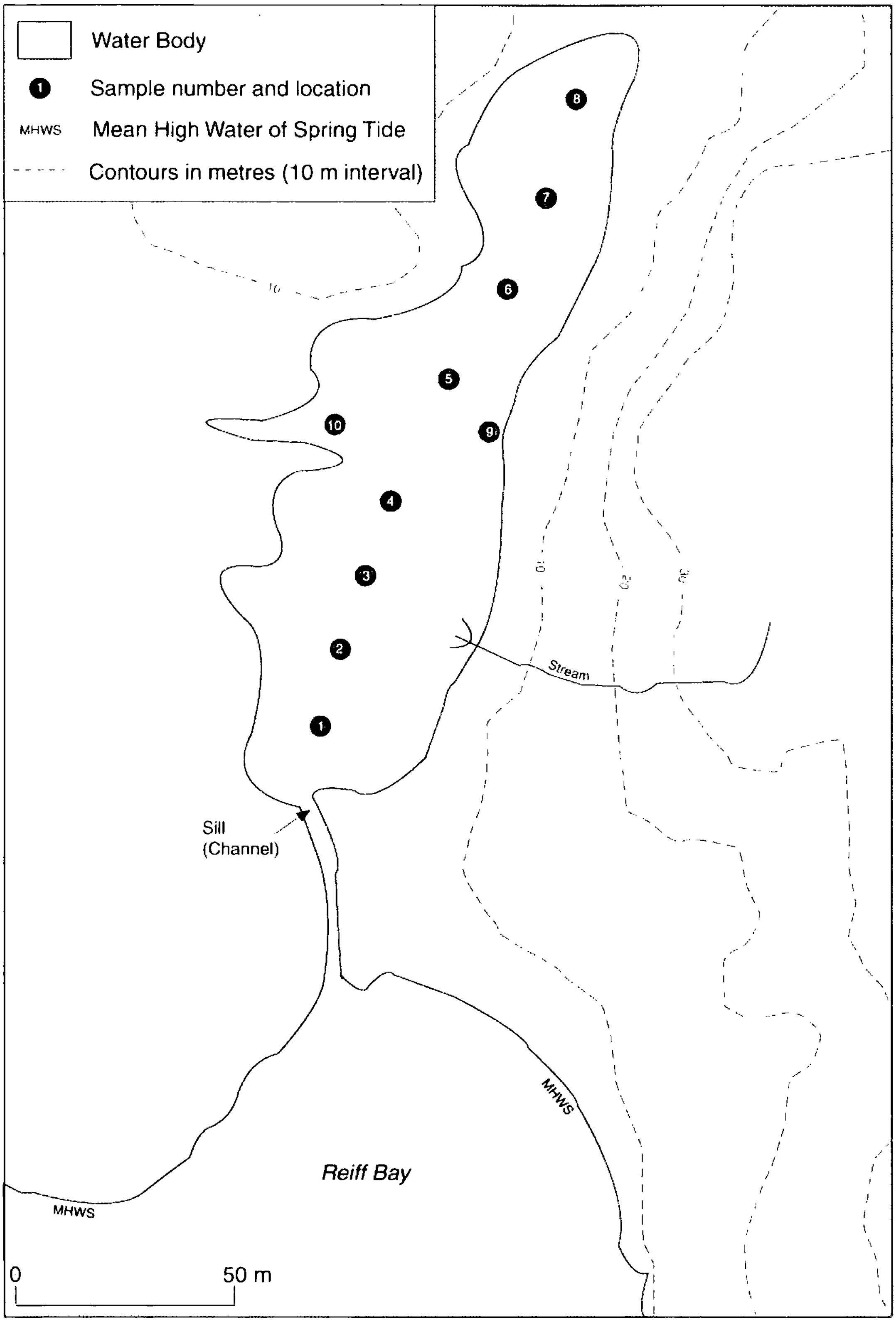


Figure 4.4.10: Loch of Reiff, Assynt.

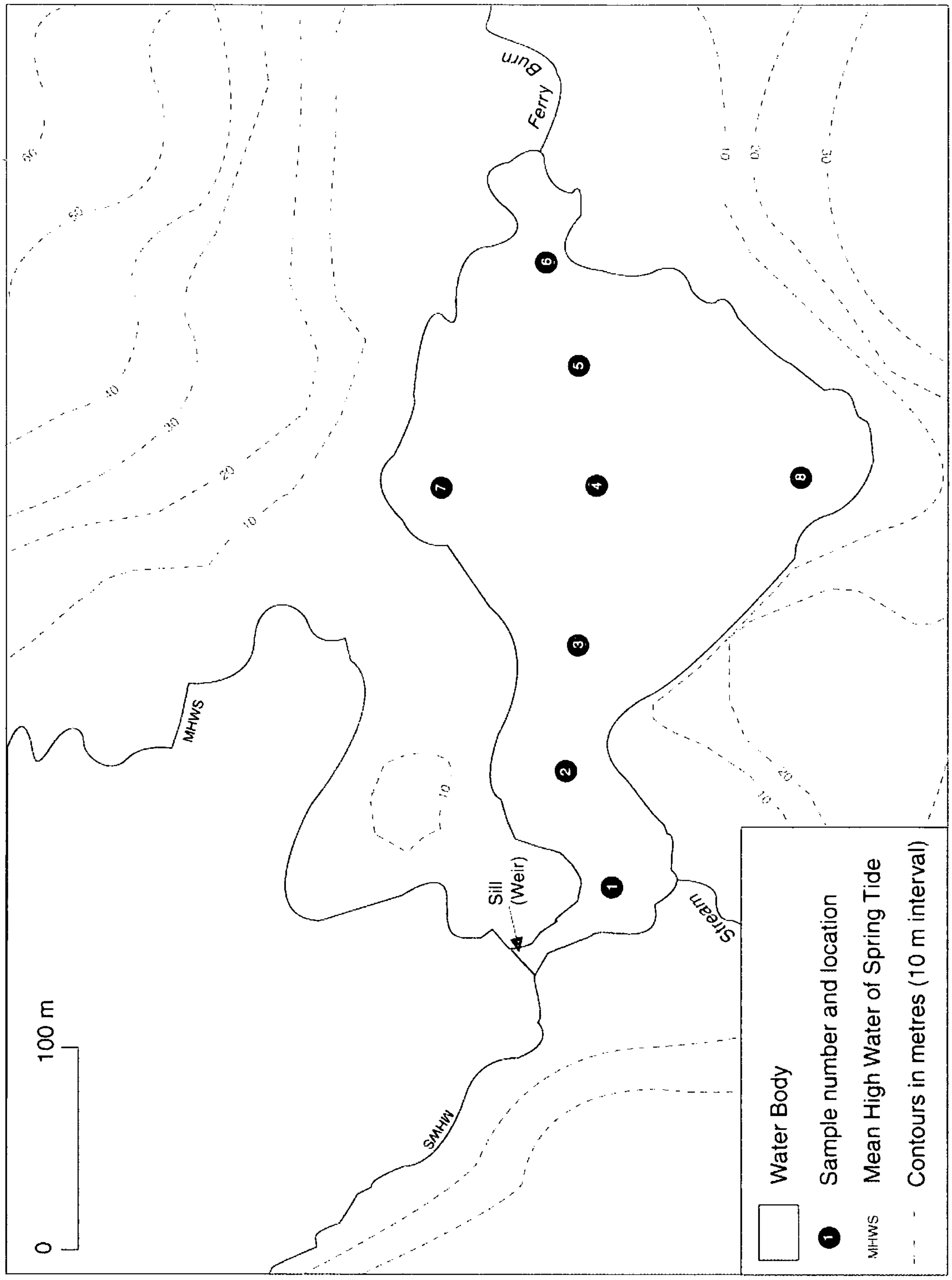


Figure 4.4.11: Lochan Sal, Assynt.

Plate 4.5: Retaining wall for Lochan Sal, Assynt, with water flowing out of the basin through a shallow notch.

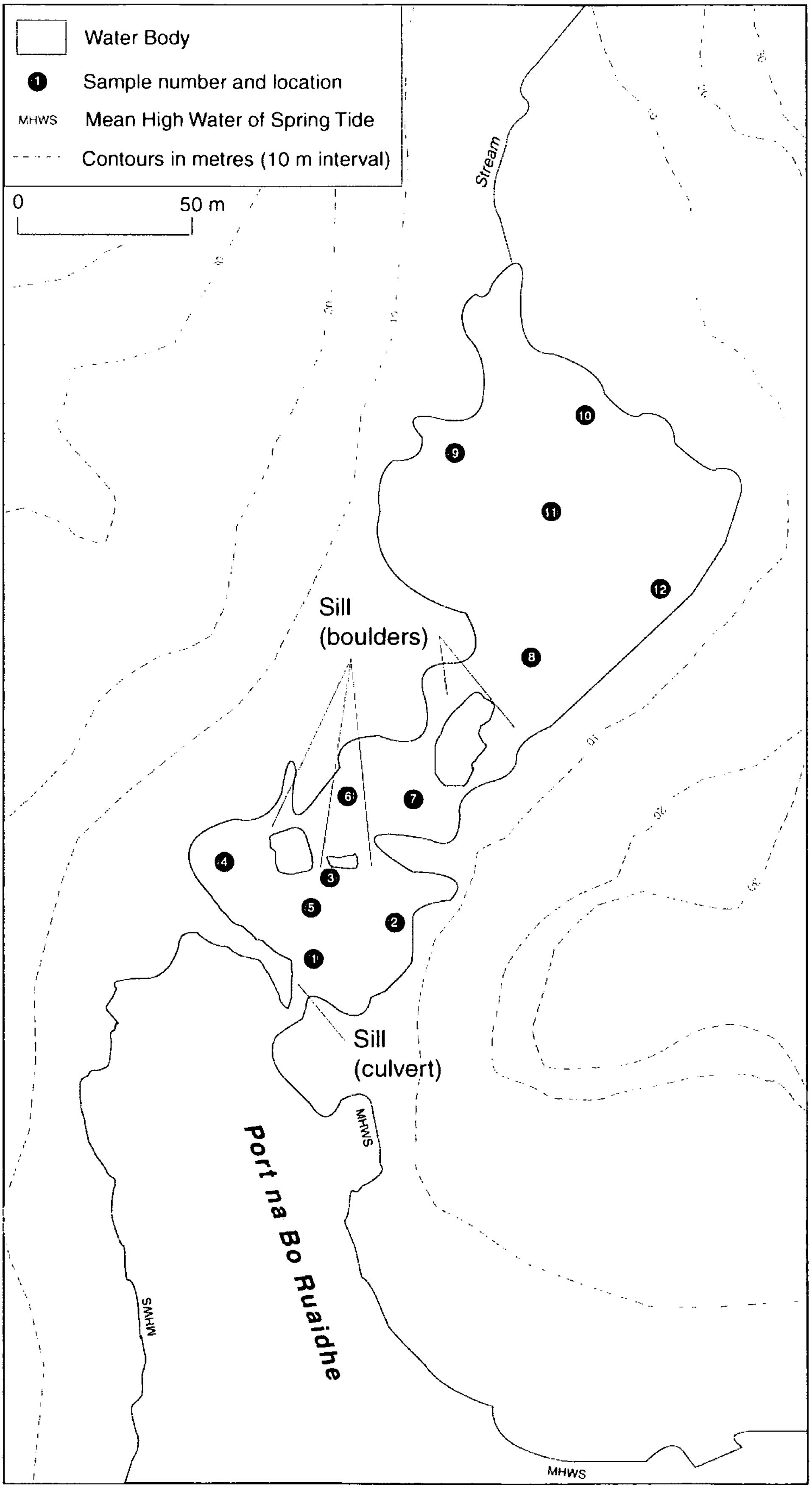


Figure 4.4.12: Loch an Eisg-brachaidh, Assynt.

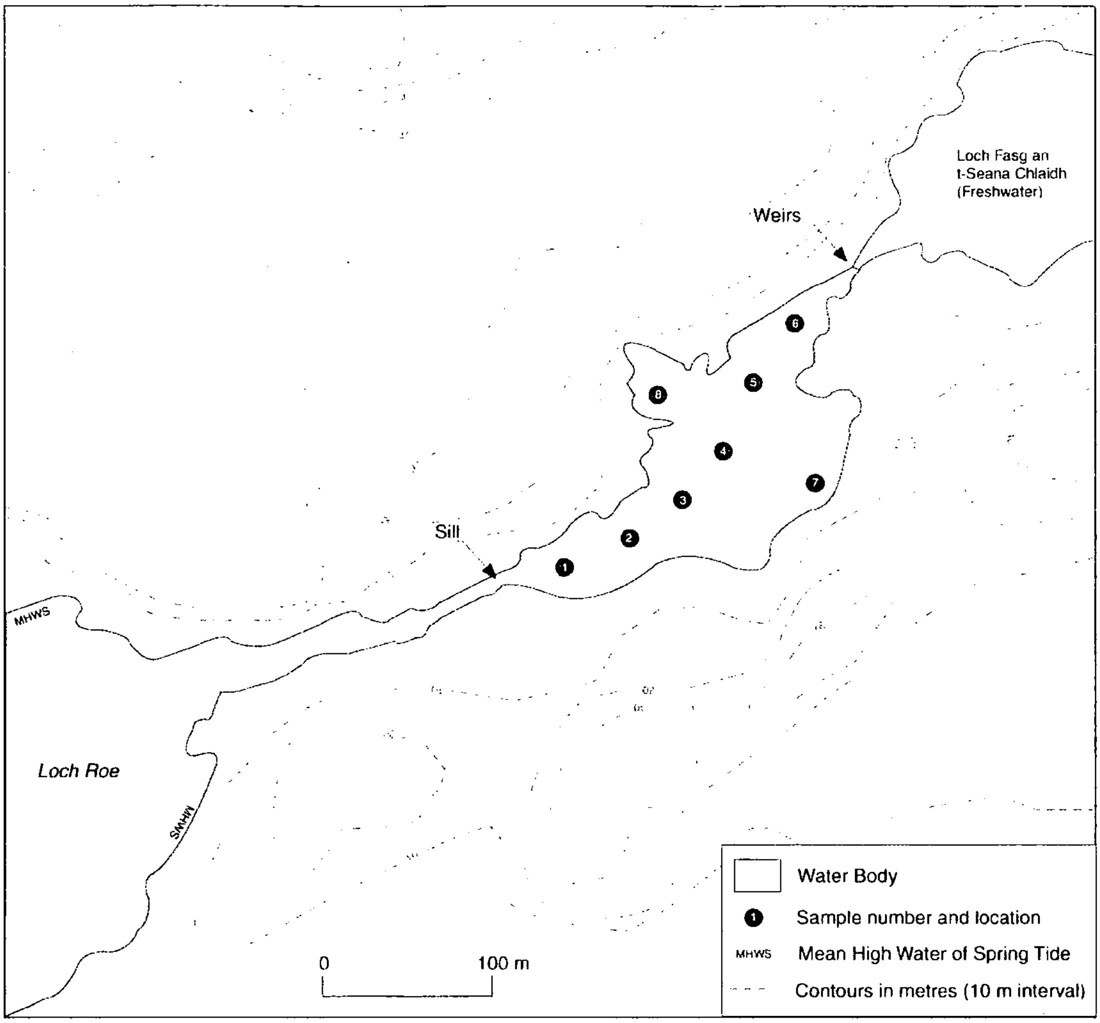


Figure 4.4.13: Loch Roe Lagoon, Assynt.

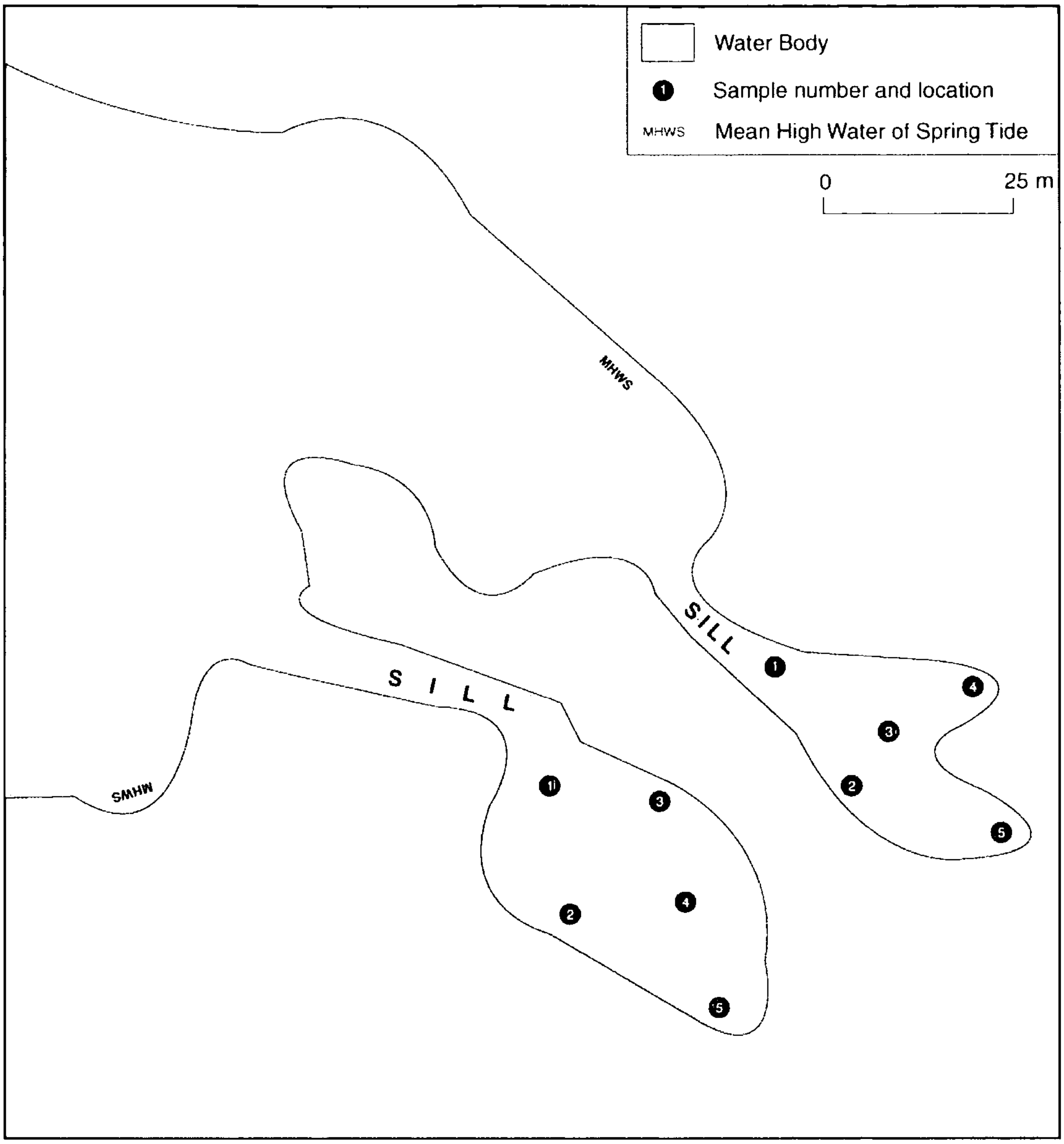


Figure 4.4.14: Oldany Lagoons, Assynt.

Plate 4.6: One of the Oldany Lagoons, Assynt, with the natural rock sill in the middle of the photograph, leading out into the open sea. This lagoon is the smallest in this study, at only *ca.* 30 m in length.

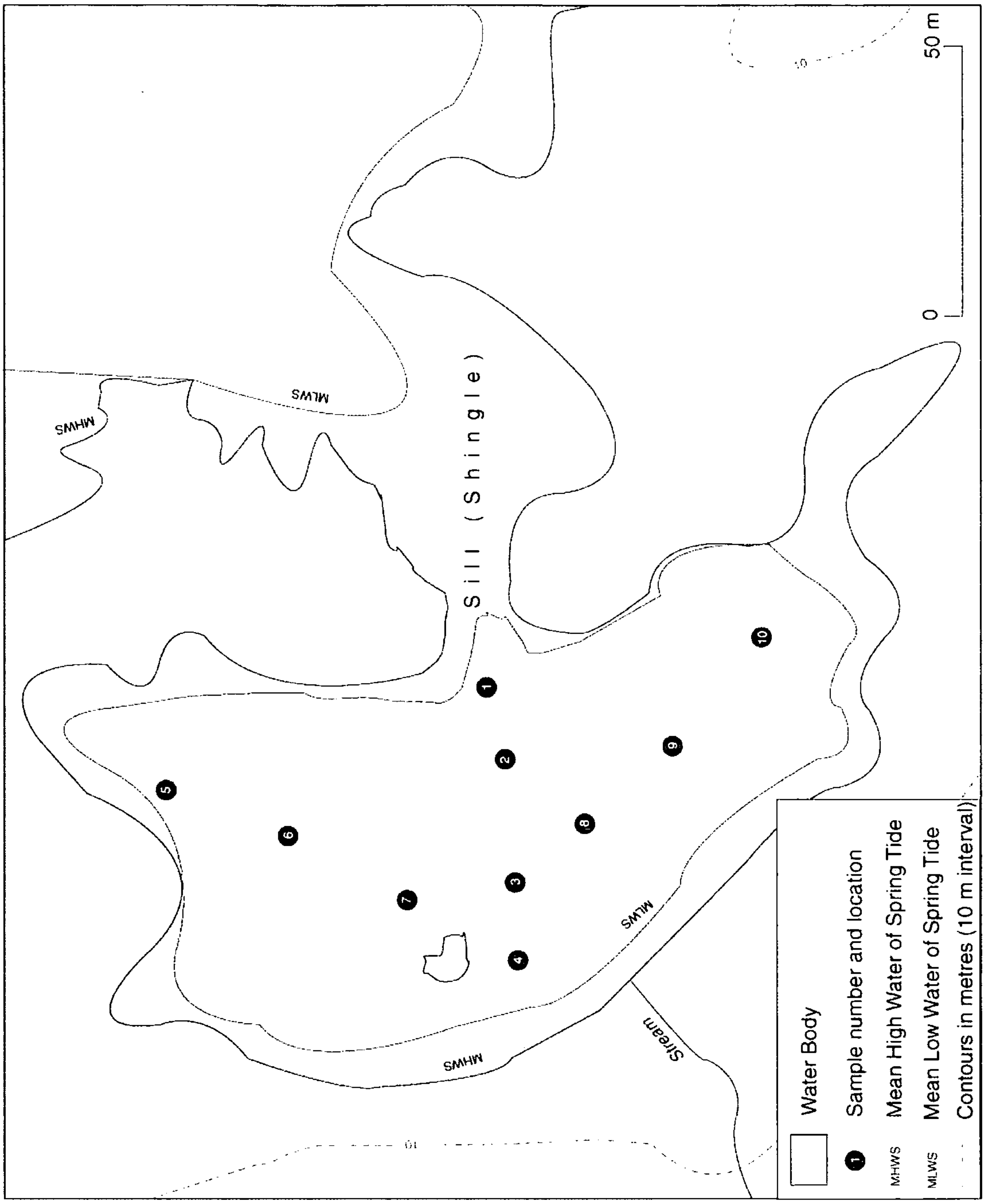


Figure 4.4.15: Loch Nedd Lagoon, Assynt.

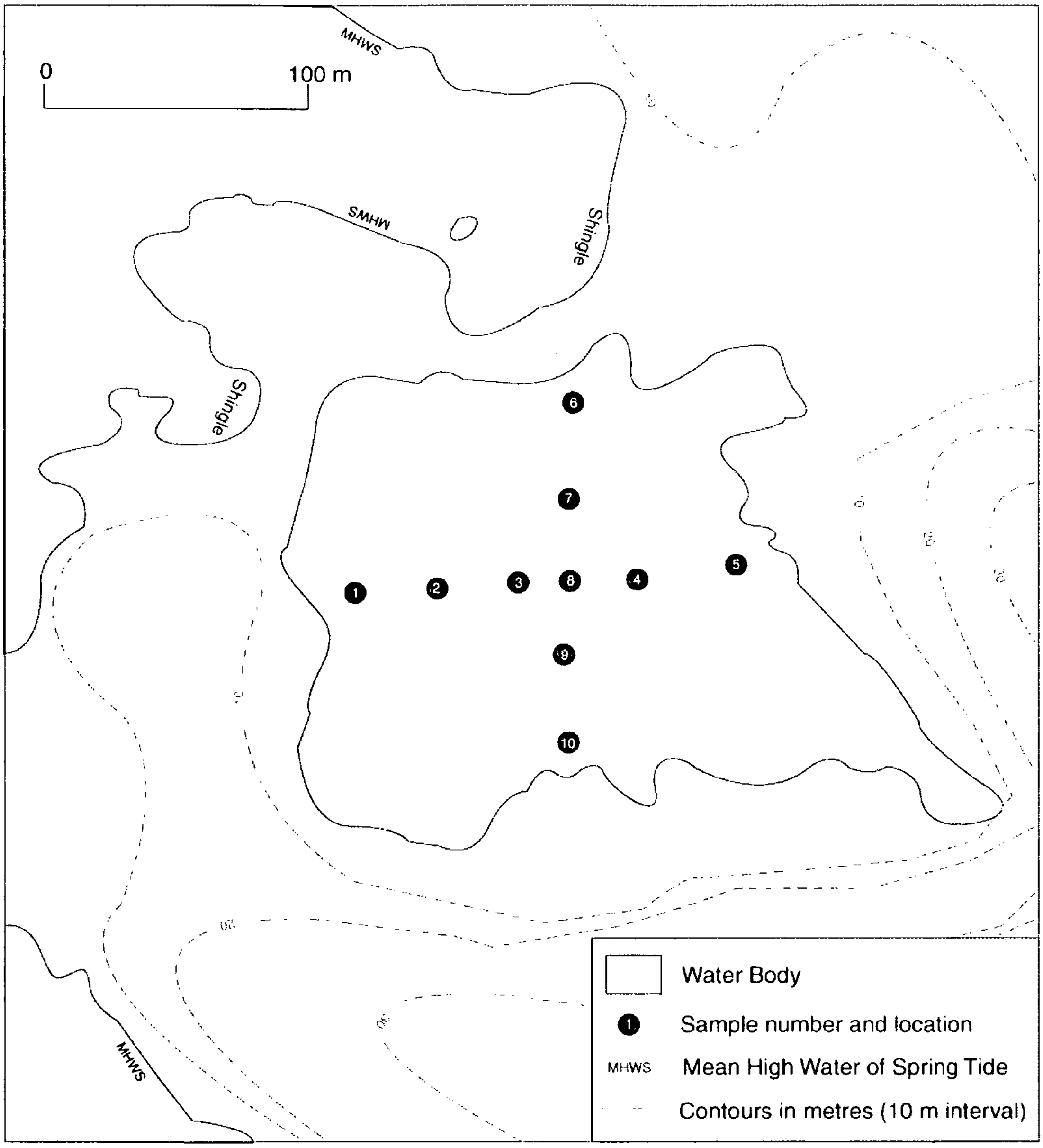


Figure 4.4.16: Lochan na Dubh Leitir, Assynt.

Plate 4.7: Lochan na Dubh Leitir, Assynt. This is a freshwater basin, held behind a thick shingle ridge (middle-right of the photograph), with relatively steep relief to the rear of the basin (middle-left of the photograph).

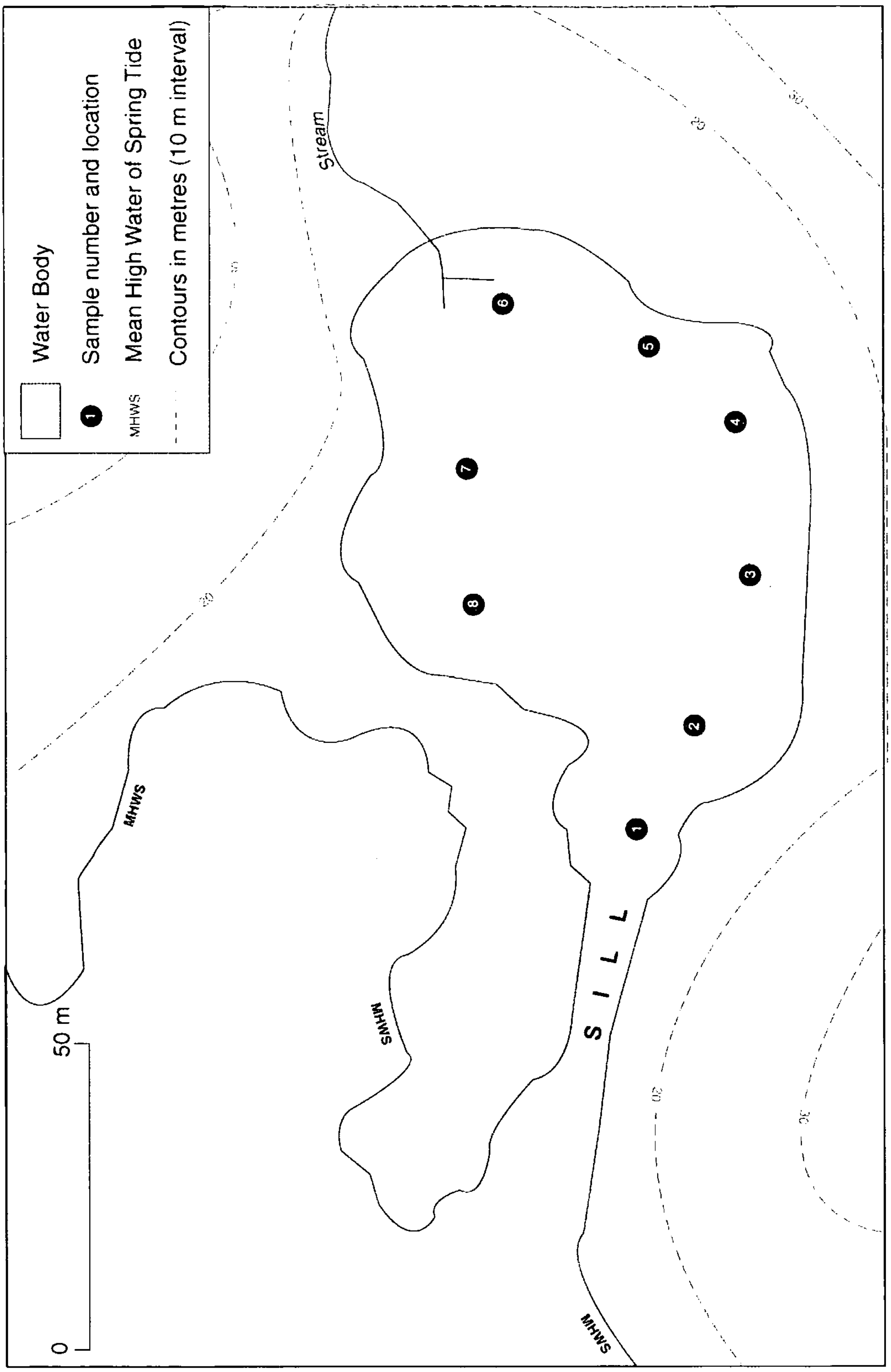


Figure 4.4.17: Duartmore, Assynt.

Plate 4.8: Duartmore Lagoon, Assynt. The sill is under-water, to the right of the photograph , with the basin to the left, separated and protected by the small rock peninsula. The steep topography surrounding the basin provides a source of freshwater input.

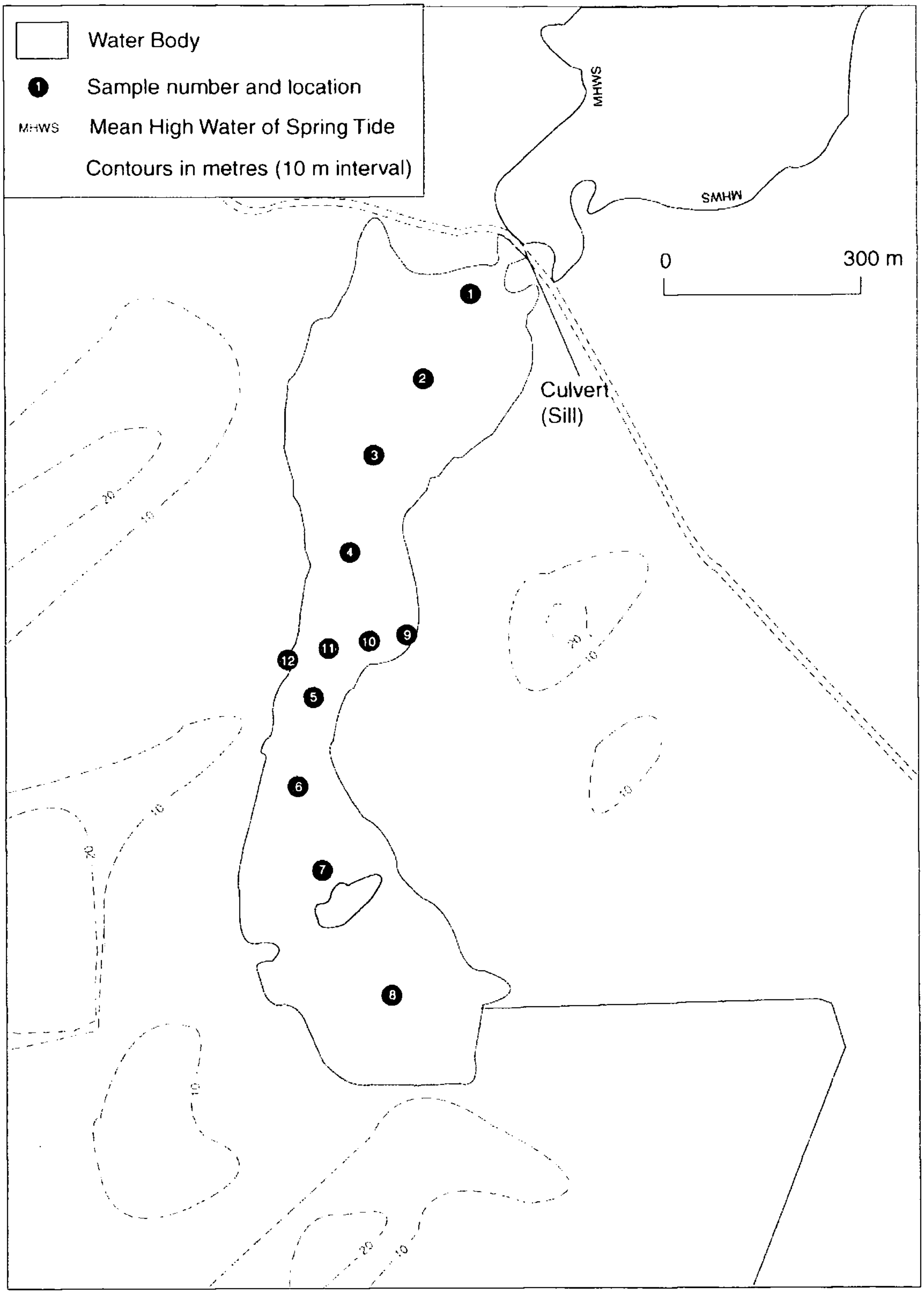


Figure 4.4.18: Caithlim Lagoon, Isle of Seil, Argyll.

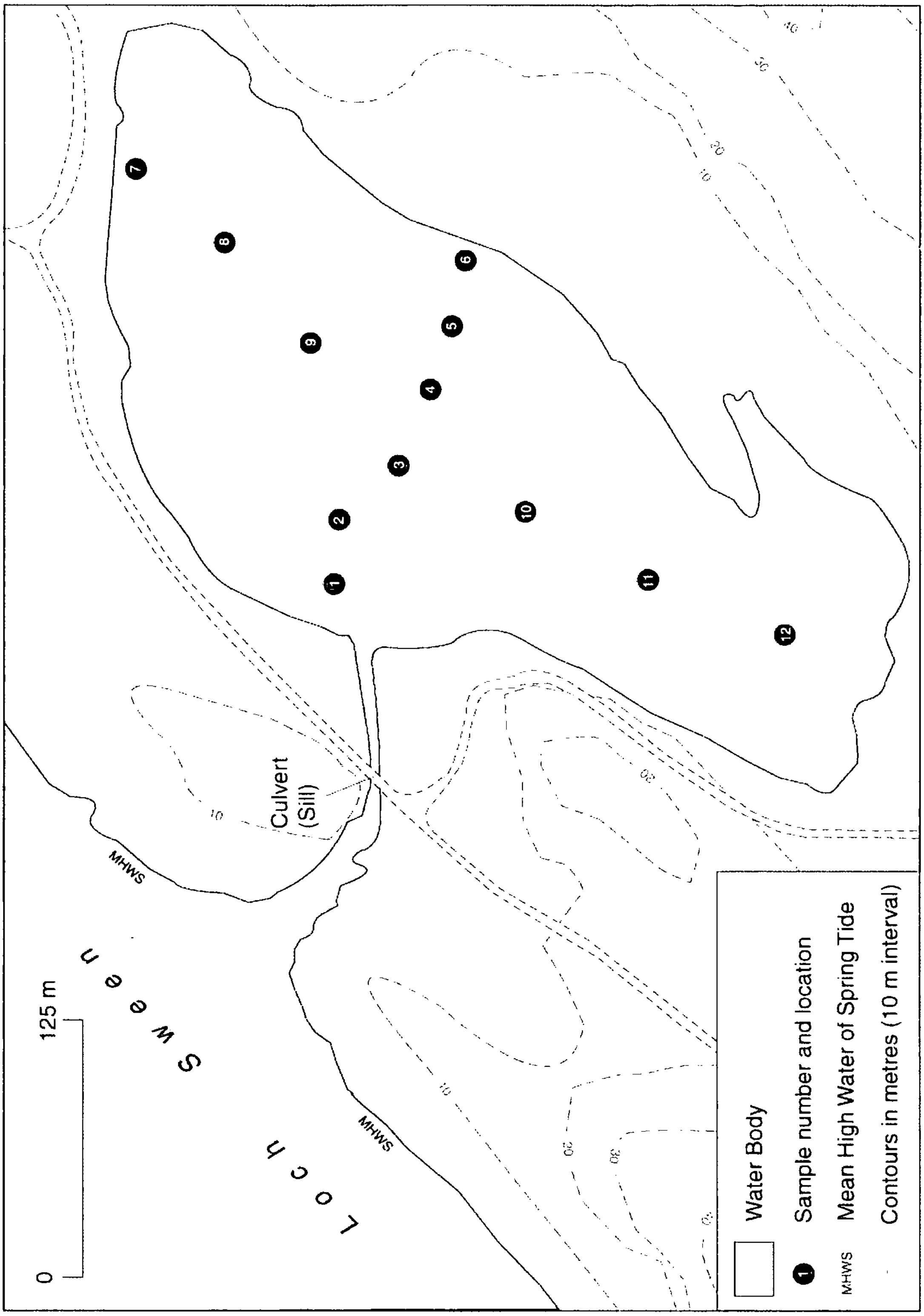


Figure 4.4.19: Craiglin Lagoon, Argyll.

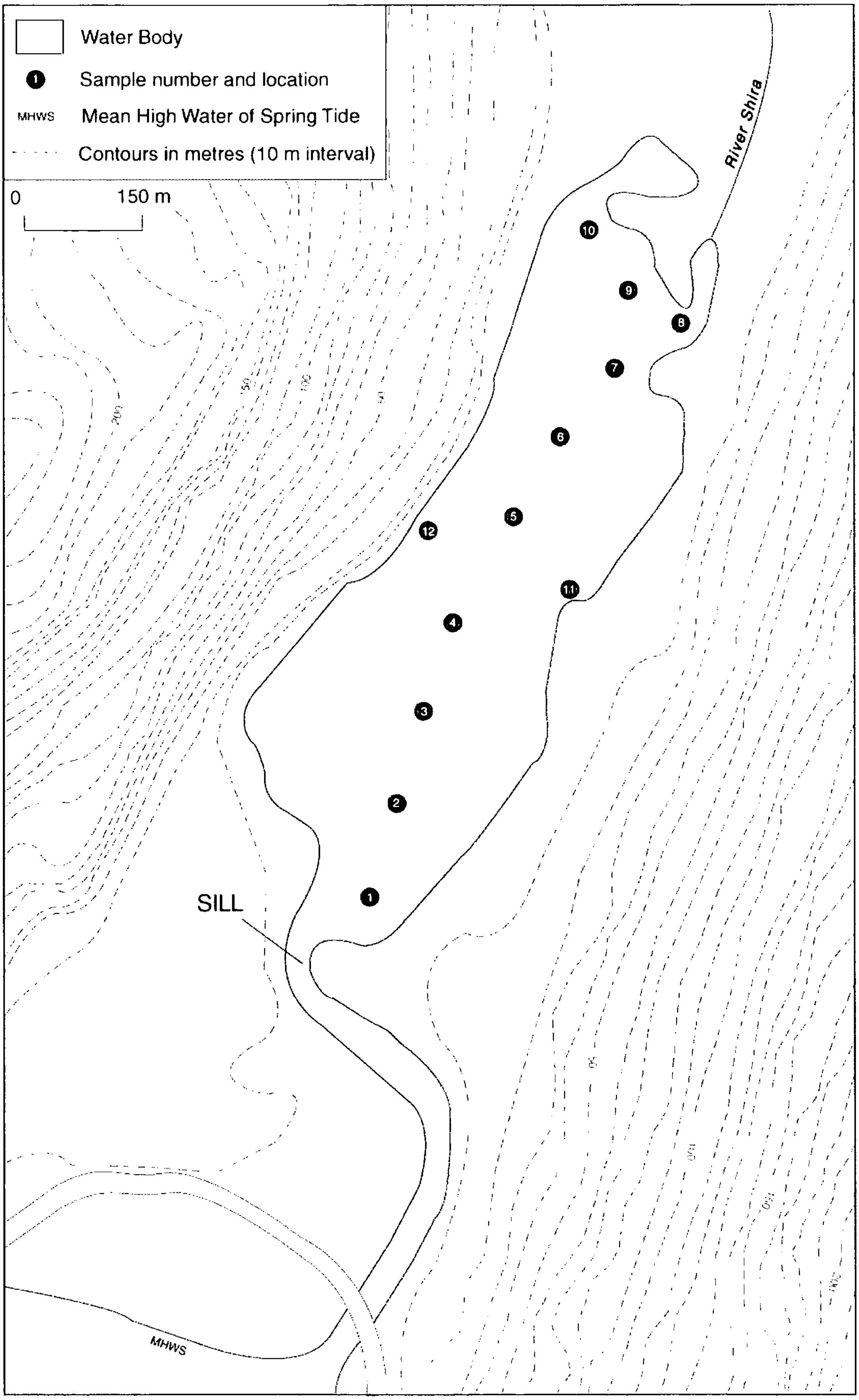


Figure 4.4.20: Dubh Loch, Argyll.

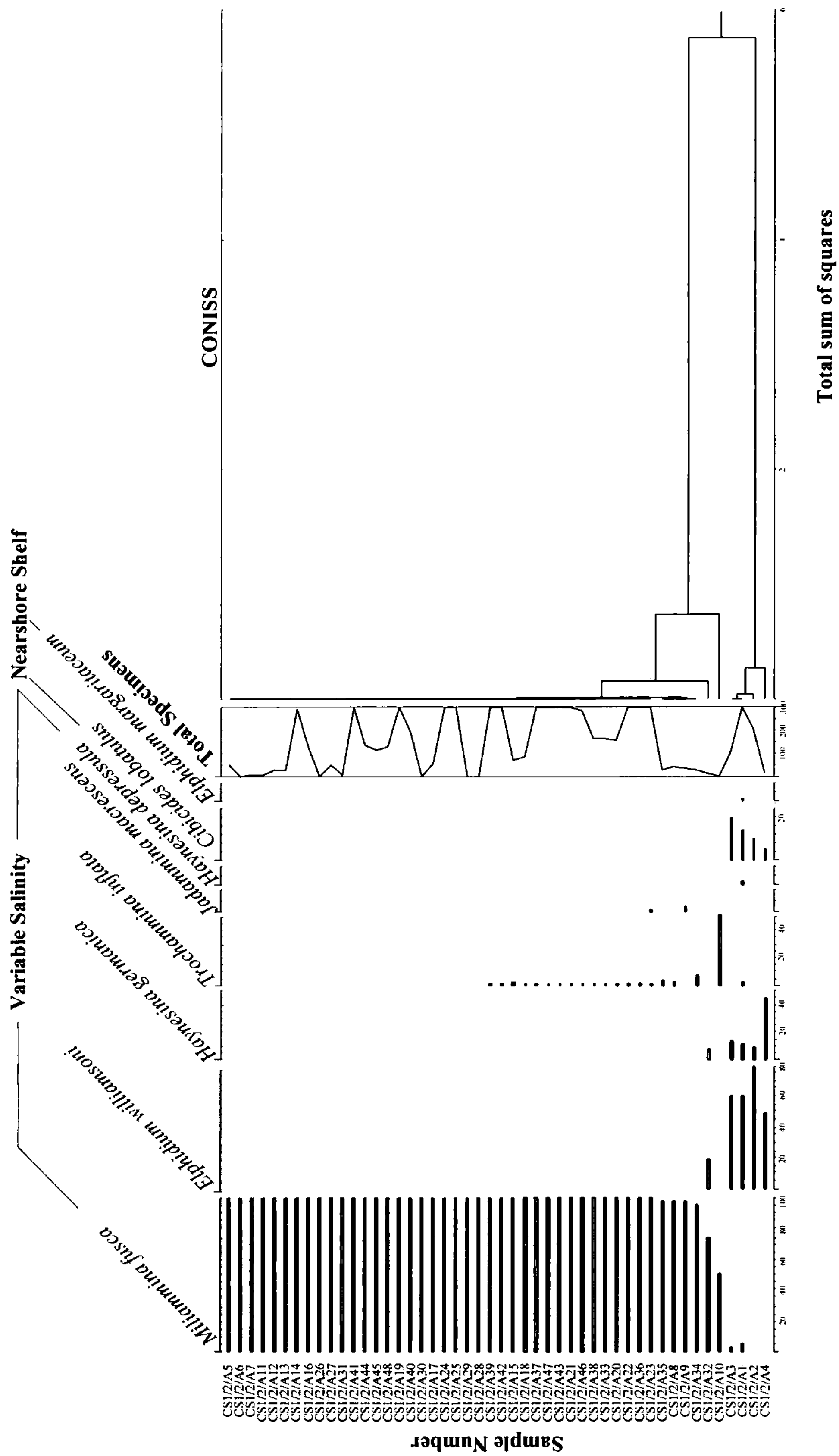


Figure 5.1.1: Foraminiferal assemblages collected from Oban nan Struthan, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

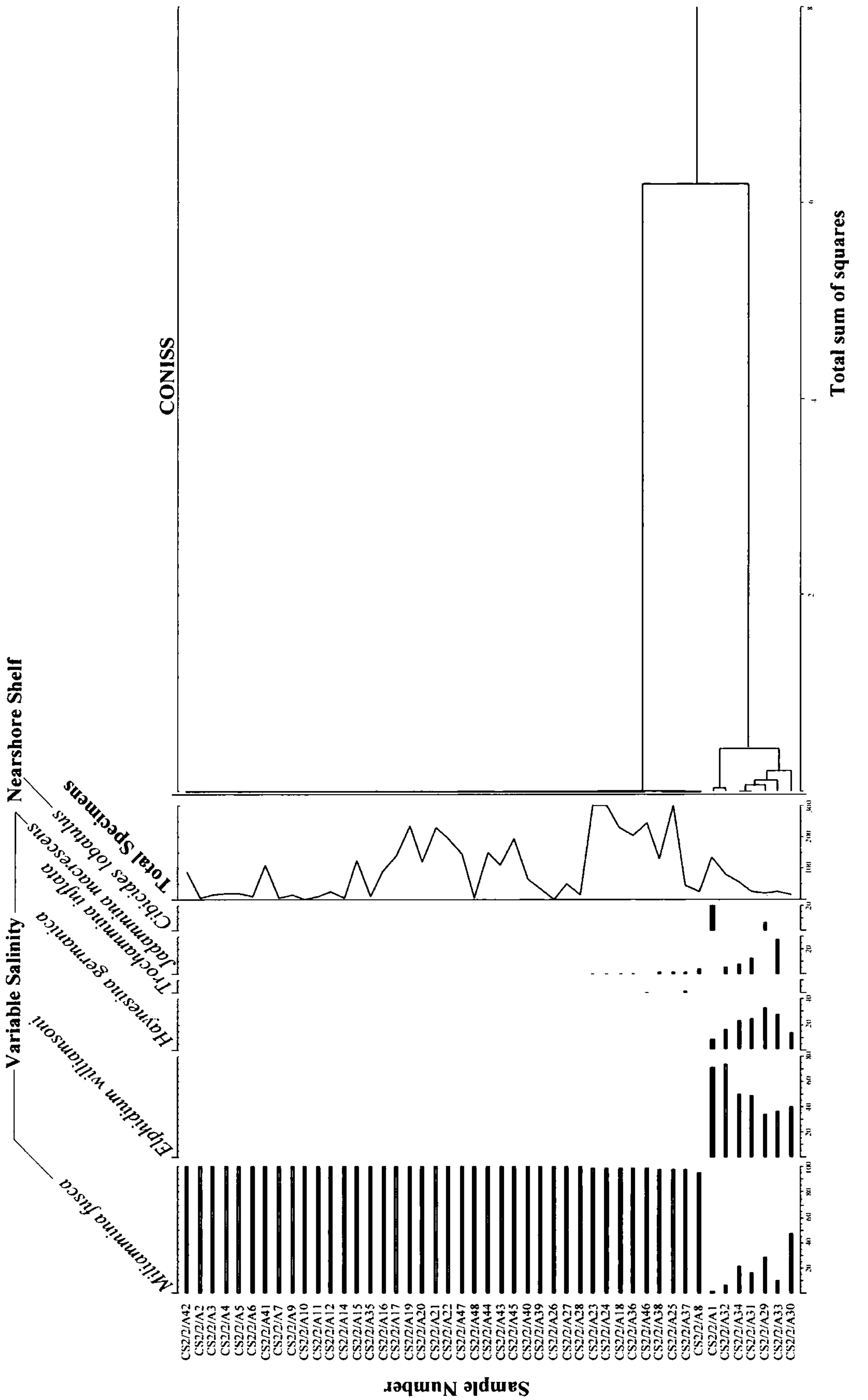


Figure 5.1.2: Foraminiferal assemblages collected from Oban nan Struthan, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

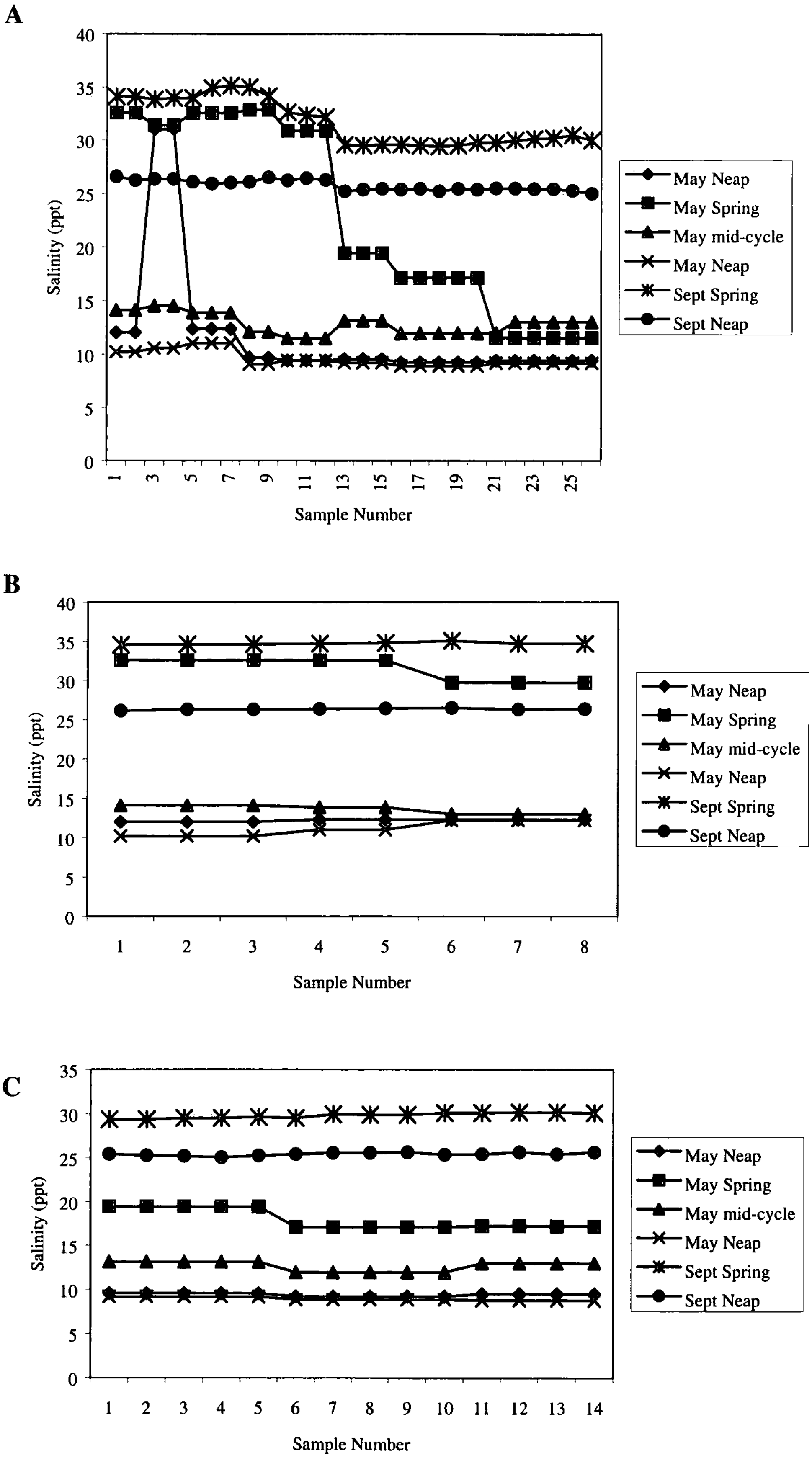


Figure 5.1.3: Salinity values for six sample periods along Transects A, B & C at Oban nan Struthan, Isle of North Uist, during May and September, 1999.

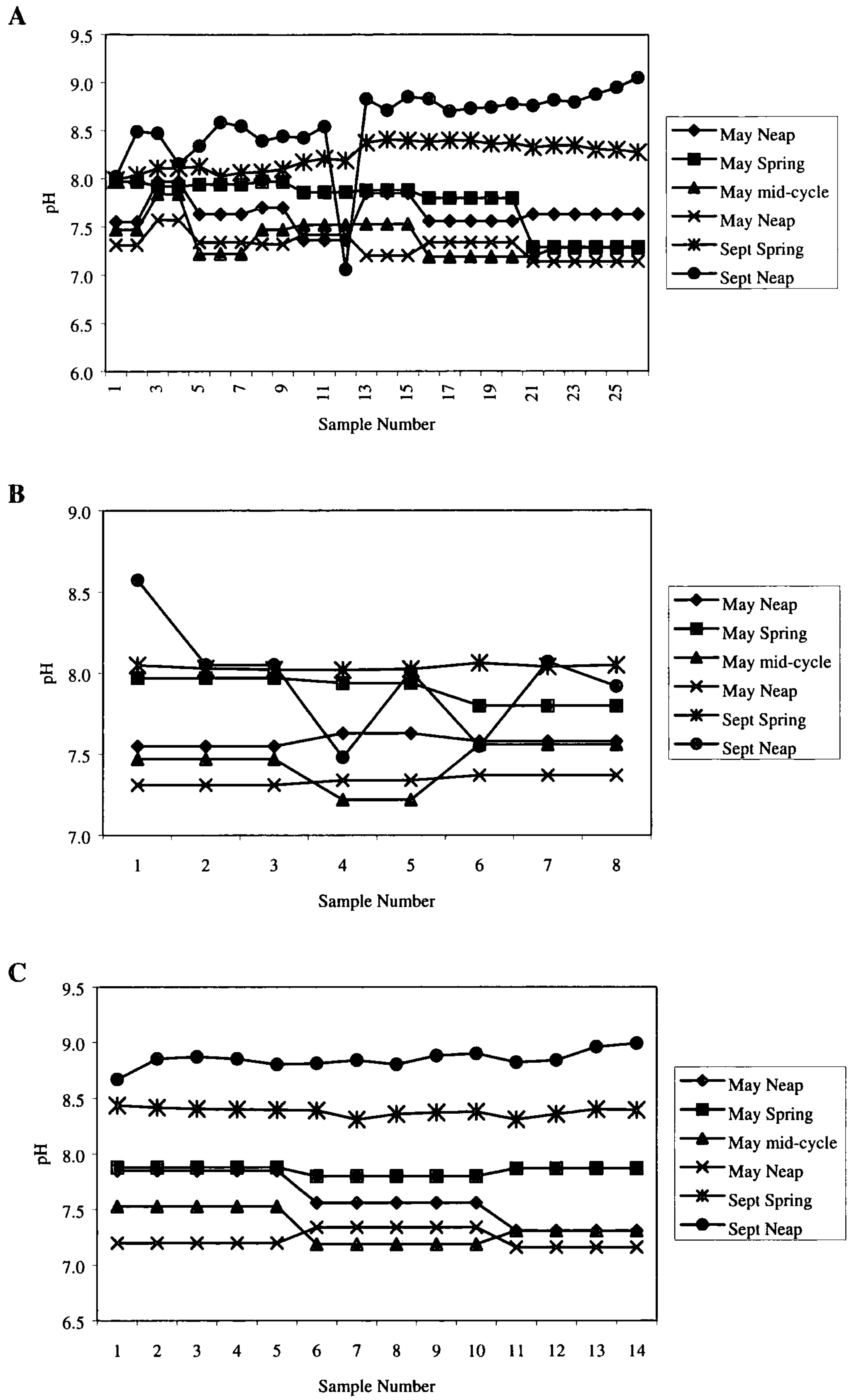
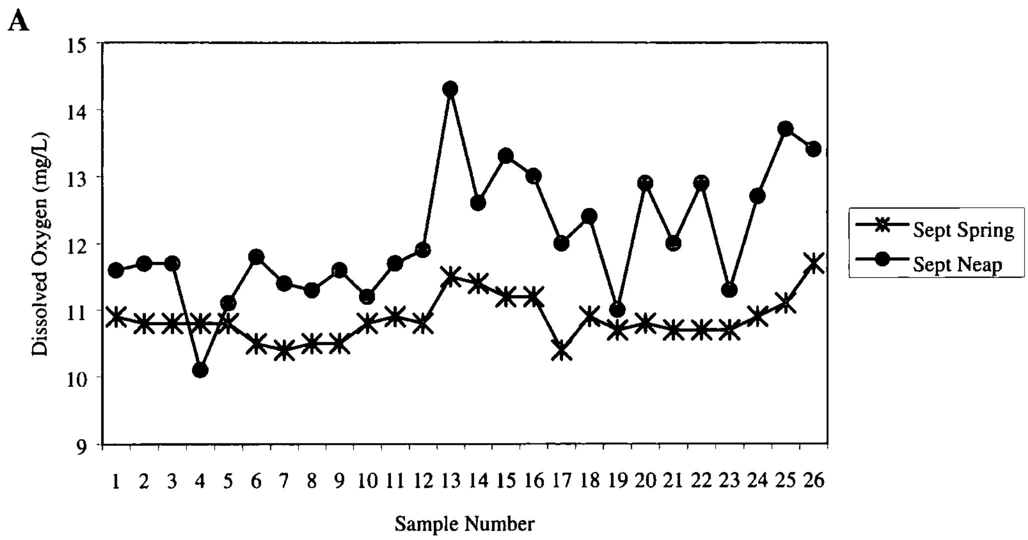
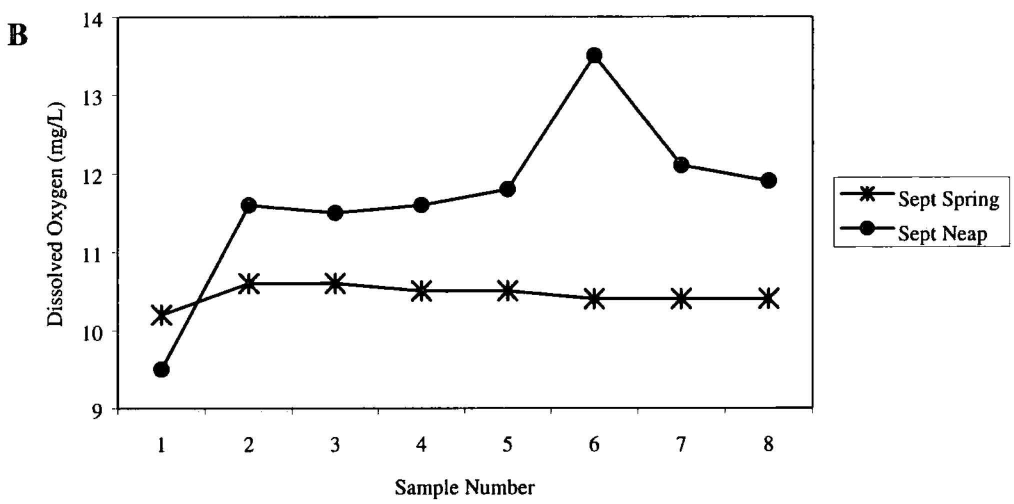


Figure 5.1.4: pH values for six sample periods along Transects A, B & C at Oban nan Struthan, Isle of North Uist, during May and September, 1999.





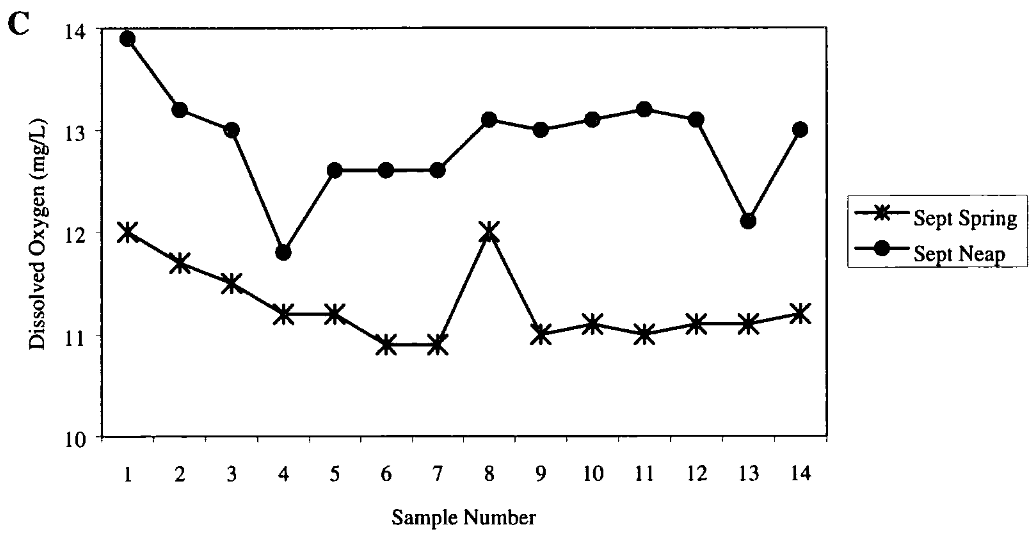
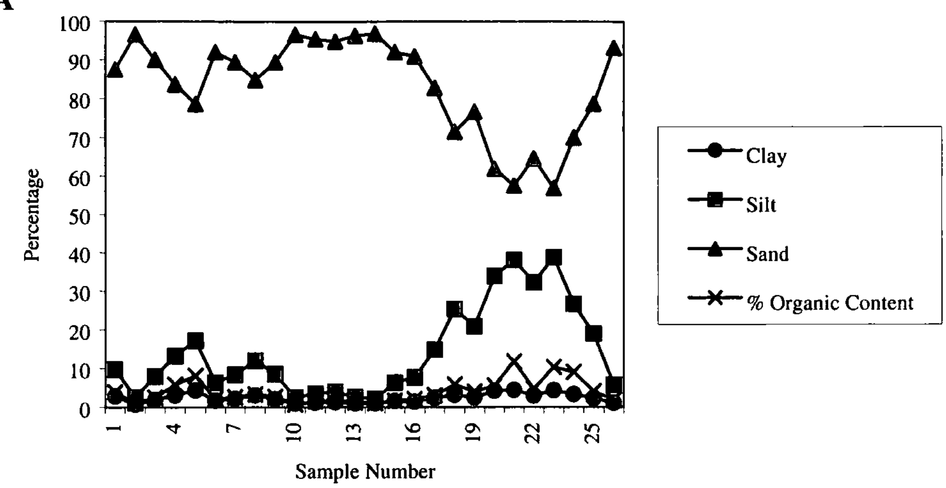
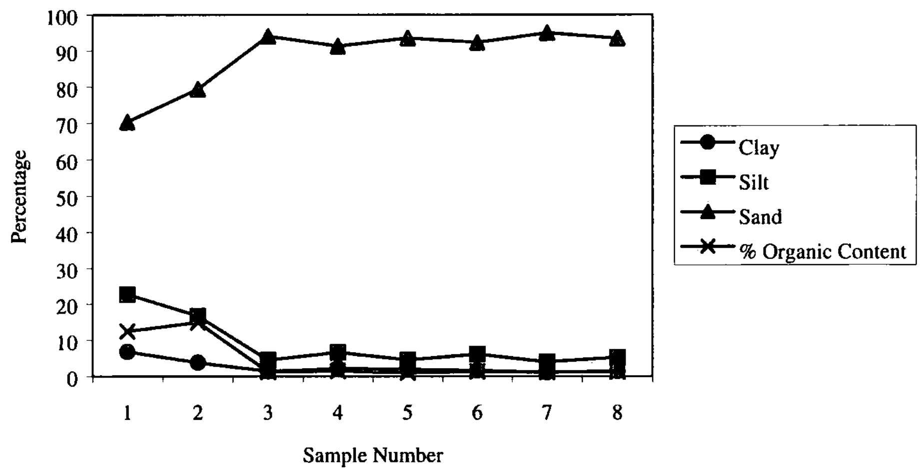


Figure 5.1.5: Dissolved Oxygen values for two sample periods along Transects A, B & C at Oban nan Struthan, Isle of North Uist, during September, 1999.

A



B



C

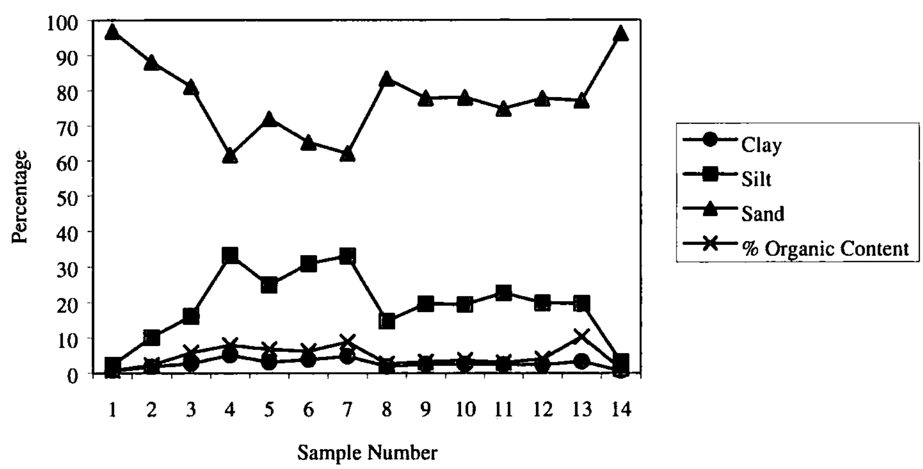


Figure 5.1.6: Particle Size and Organic content percentage data for Transects A, B & C, Oban nan Struthan, Isle of North Uist.

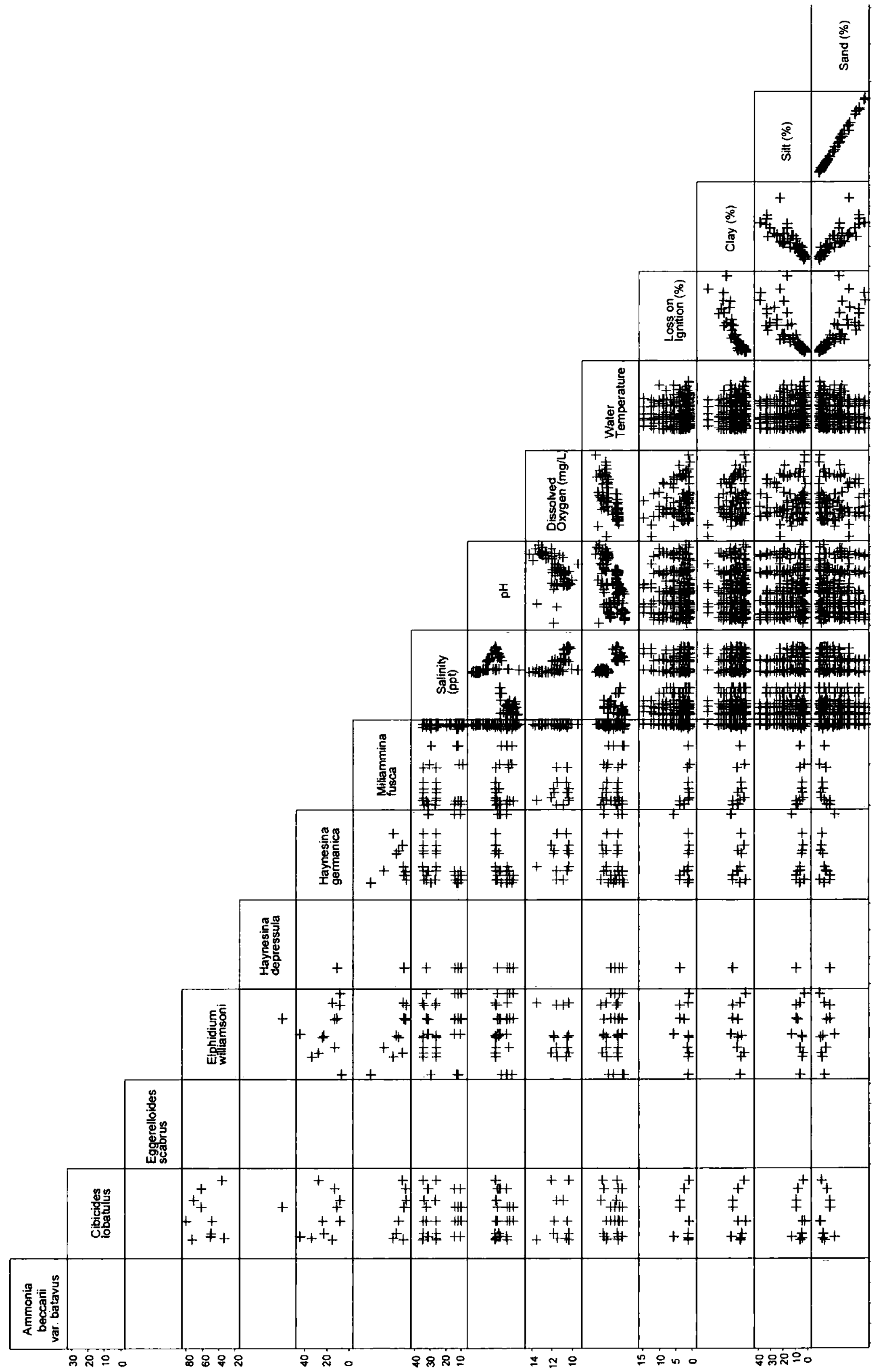


Figure 5.1.7 Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Oban nan Struthan, Isle of North Uist.

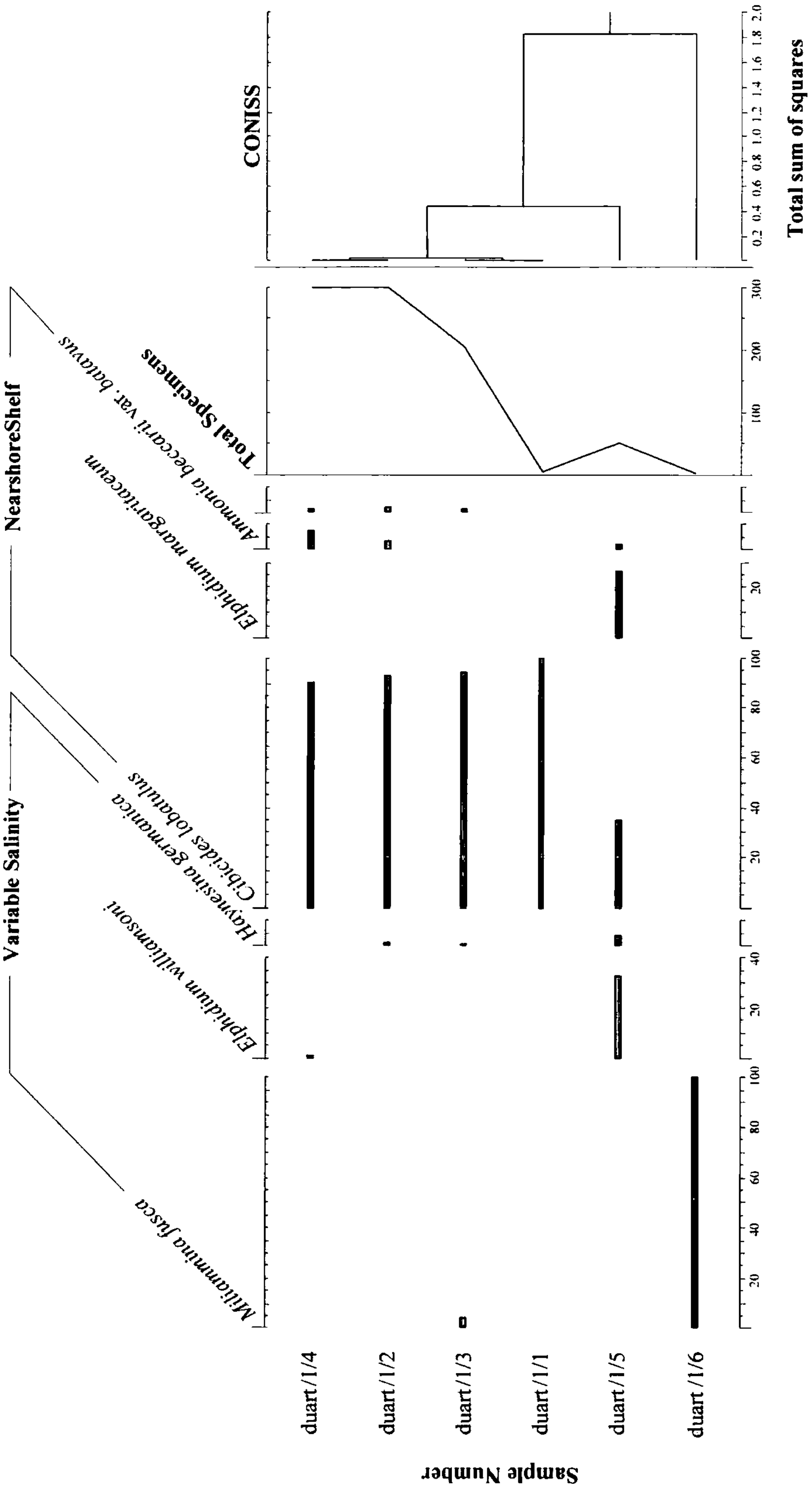


Figure 5.2.1: Foraminiferal assemblages collected from Duartmore Lagoon, Assynt, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

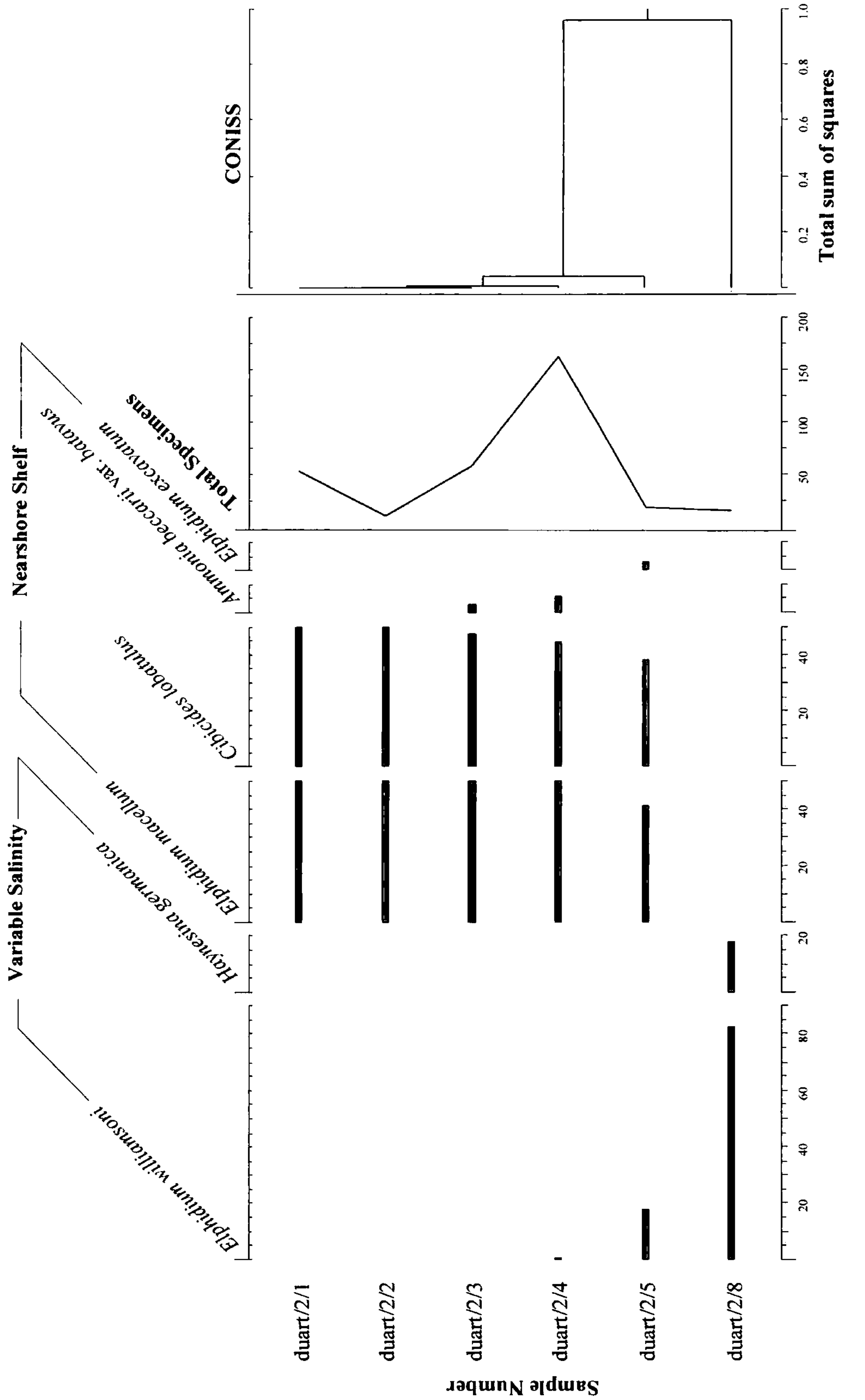


Figure 5.2.2: Foraminiferal assemblages collected from Duartmore Lagoon, Assynt, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

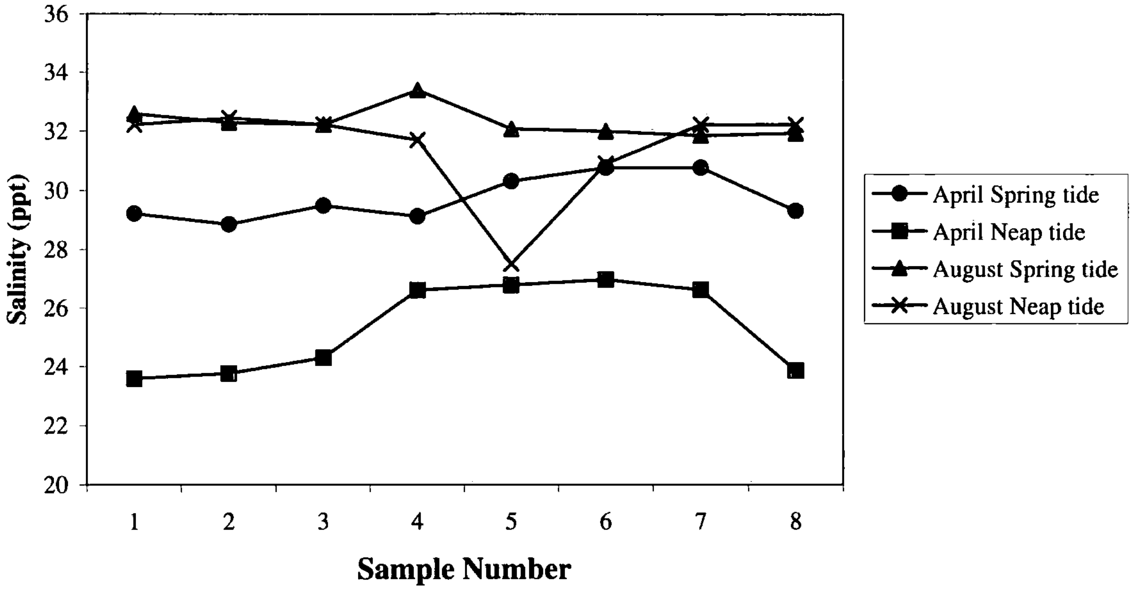


Figure 5.2.3 Salinity conditions during four sample periods for Duartmore Lagoon, Assynt, during April and August 2000.

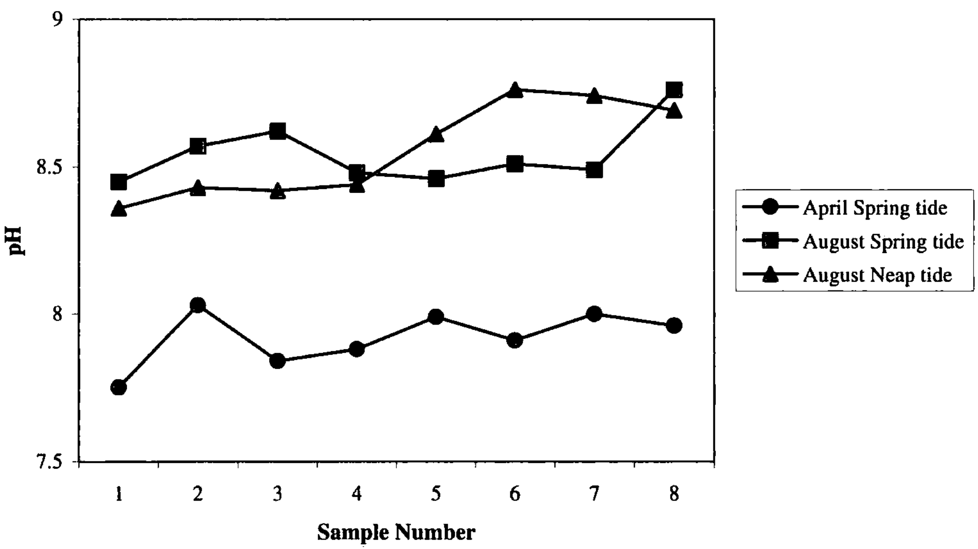


Figure 5.2.4 pH conditions during three sample periods for Duartmore Lagoon, Assynt, during April and August 2000. April Neap tide data is not available, owing to meter malfunction.

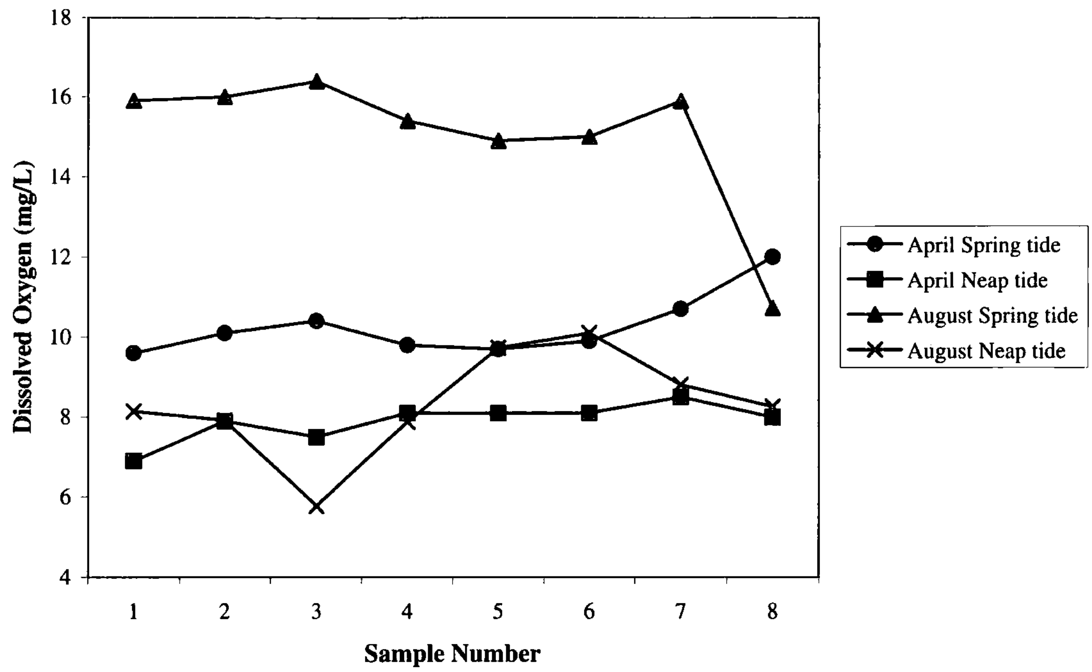


Figure 5.2.5 Dissolved oxygen conditions during four sample periods for Duartmore Lagoon, Assynt, during April and August 2000.

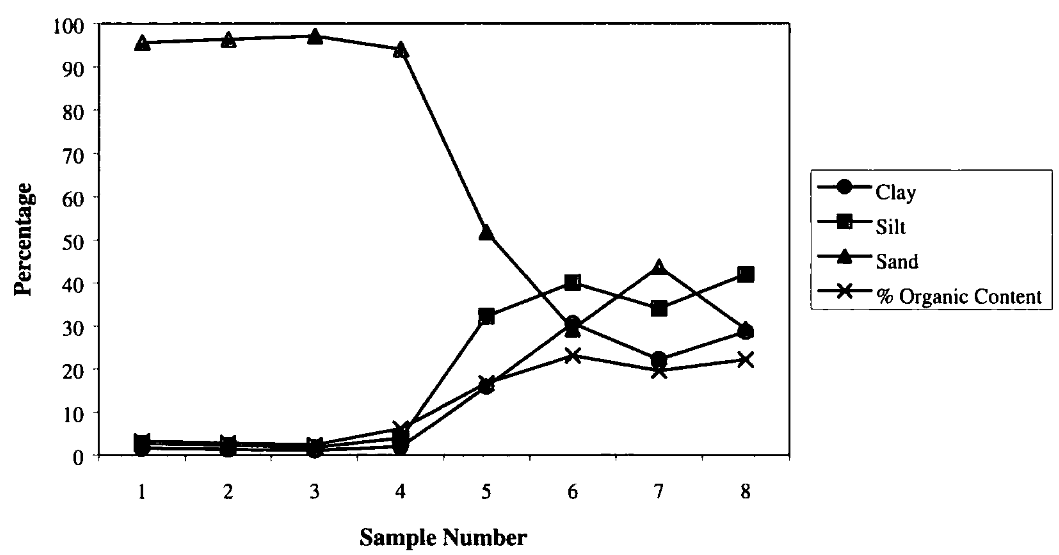


Figure 5.2.6 Particle size and organic content percentage data for Duartmore Lagoon, Assynt.

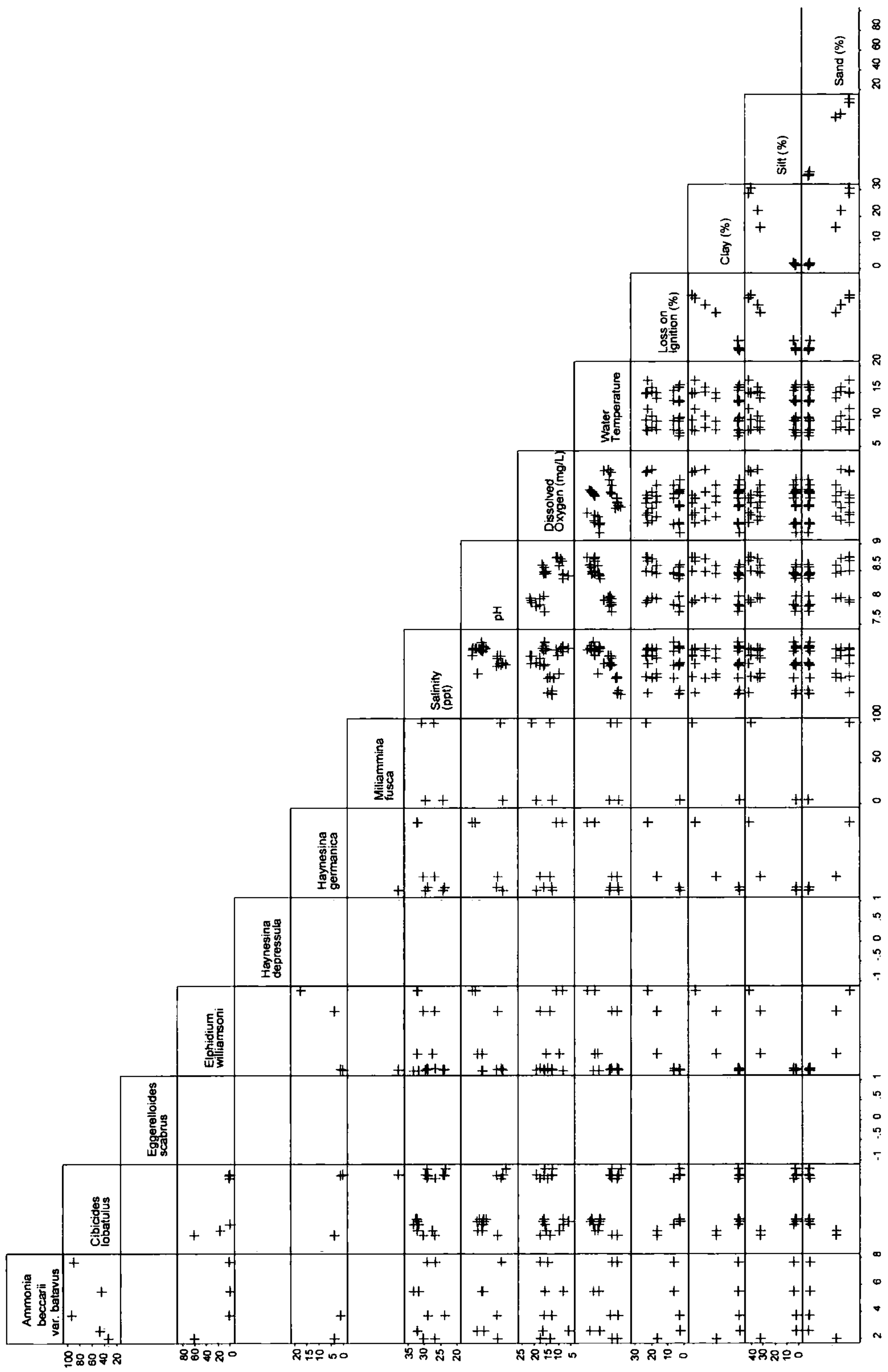


Figure 5.2.7 Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Duartmore Lagoon, Assynt.

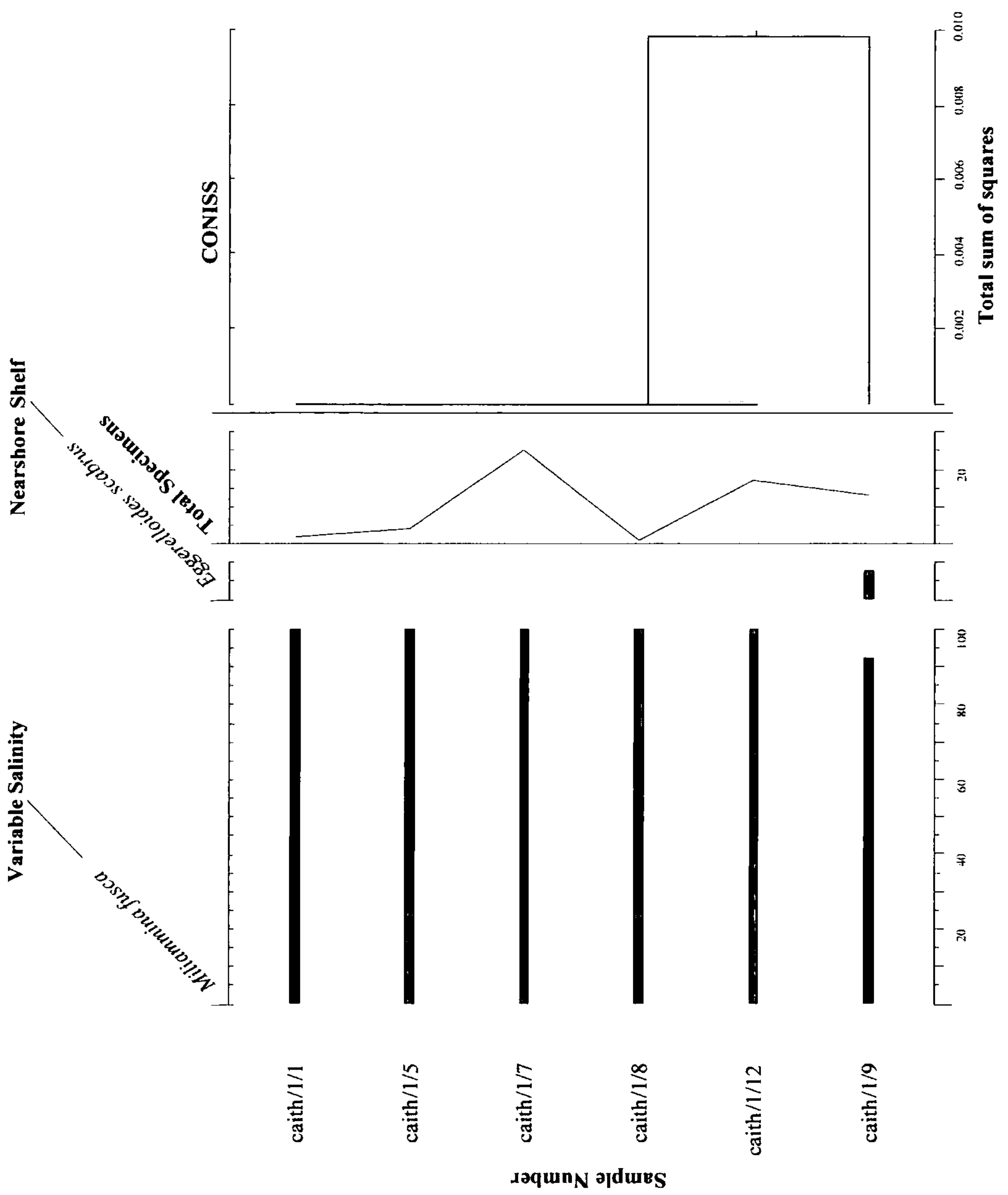


Figure 5.3.1: Foraminiferal assemblages collected from Caithlim Lagoon, Argyll, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

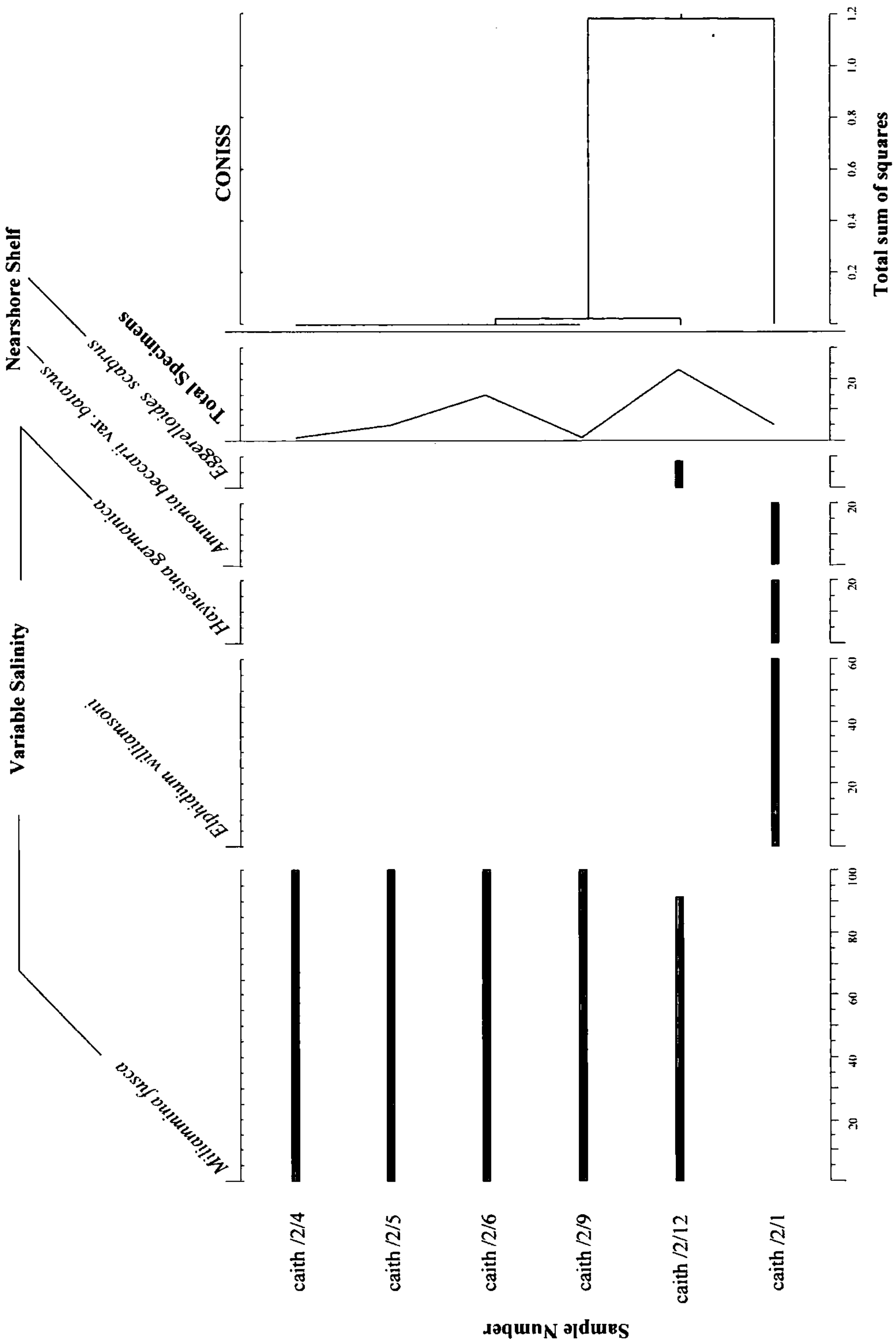


Figure 5.3.2: Foraminiferal assemblages collected from Caithlim Lagoon, Argyll, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

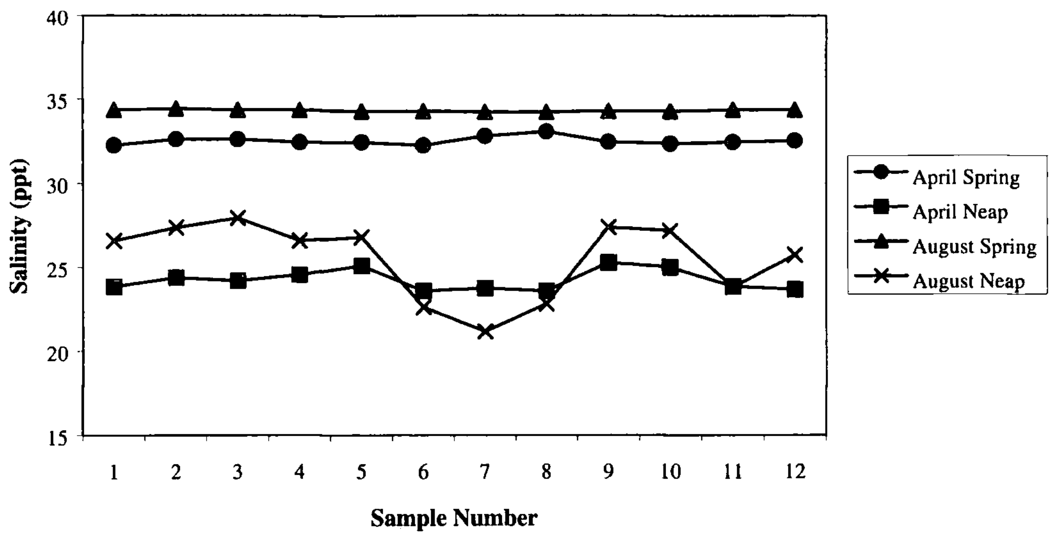


Figure 5.3.3: Salinity conditions during four sample periods for Caithlim Lagoon, Argyll, during April and August 2000.

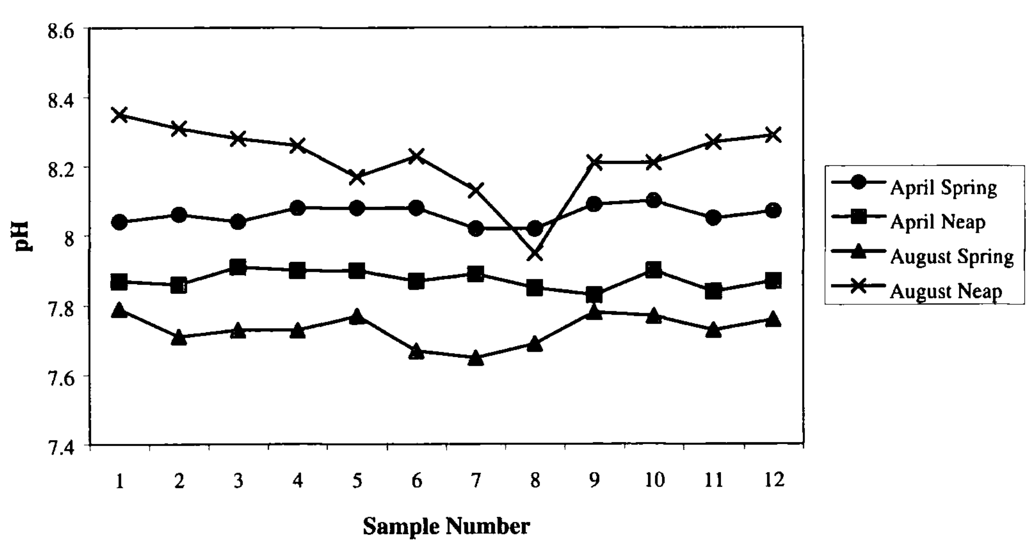


Figure 5.3.4: pH conditions during four sample periods for Caithlim Lagoon, Argyll, during April and August 2000.

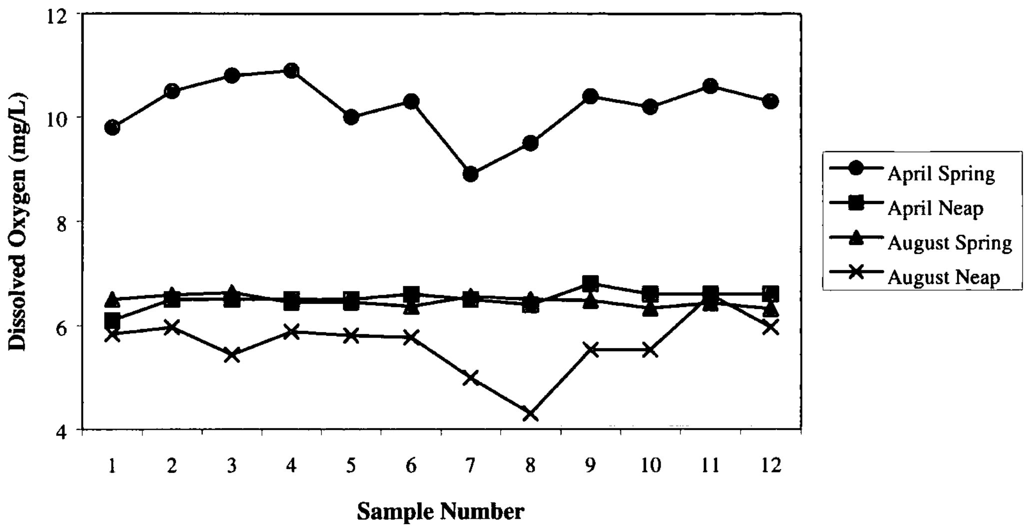


Figure 5.3.5: Dissolved oxygen conditions during four sample periods for Caithlim Lagoon, Argyll, during April and August 2000.

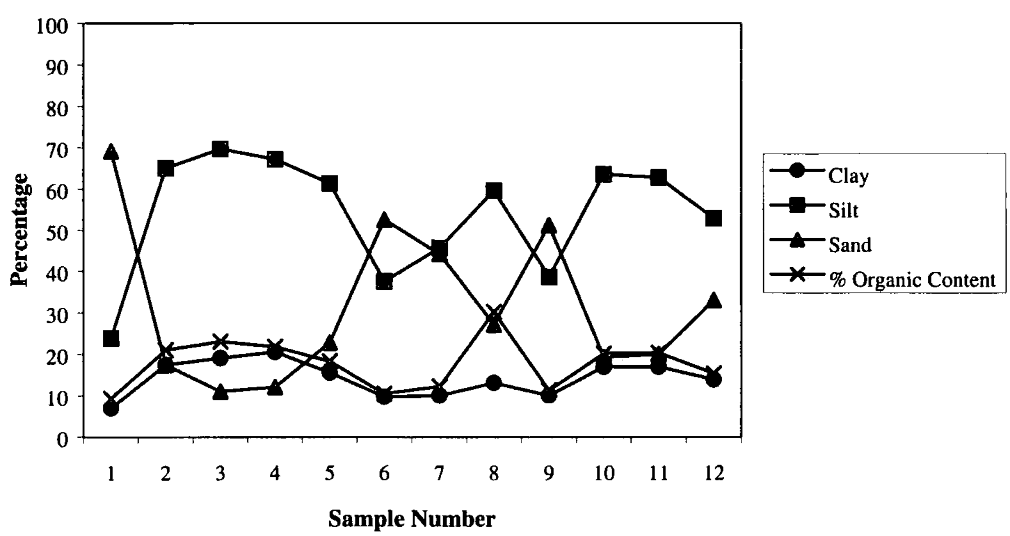


Figure 5.3.6: Particle Size and Organic content percentage data for Caithlim Lagoon, Argyll.

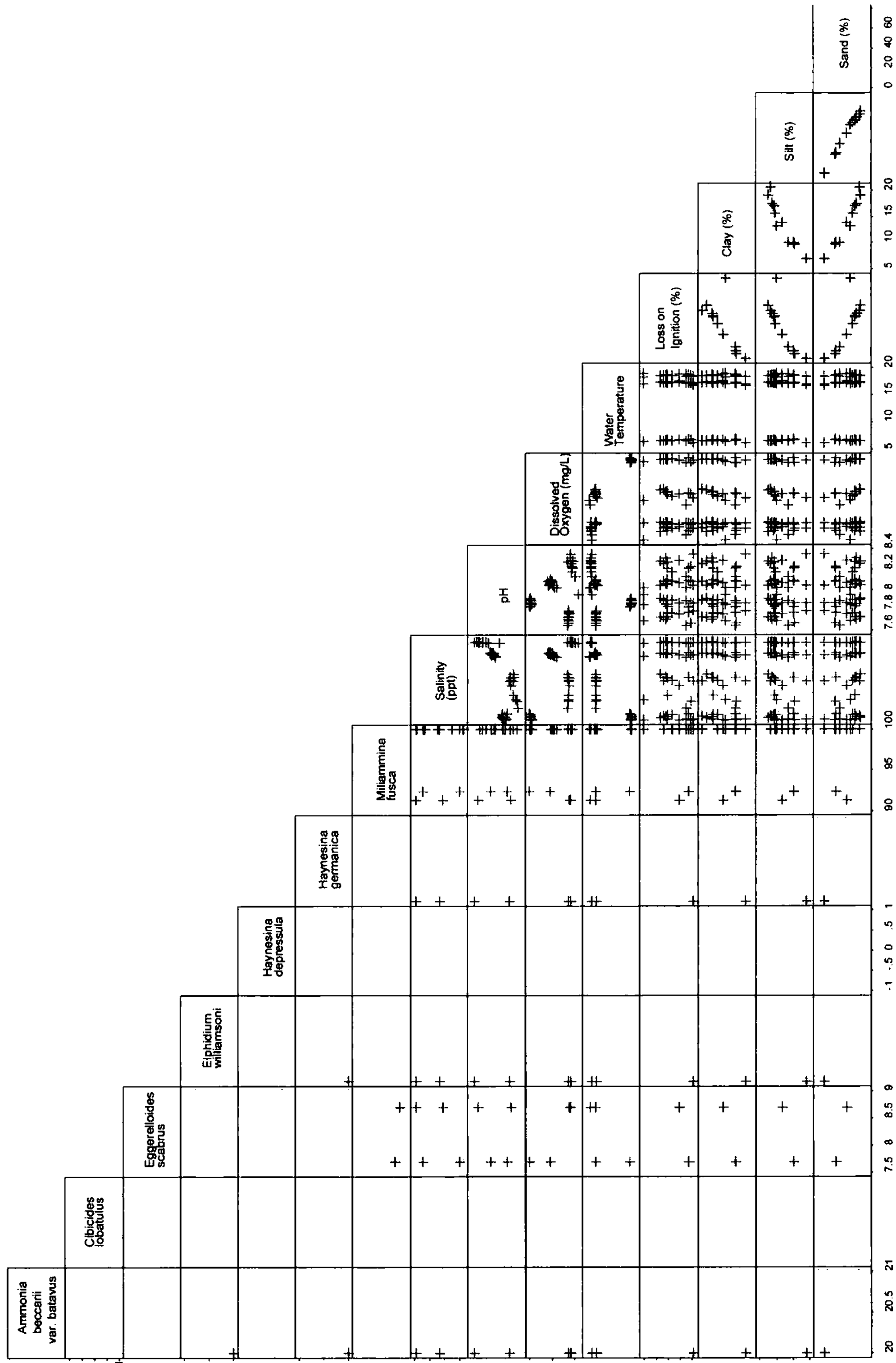


Figure 5.3.7: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Caithlim Lagoon, Argyll.

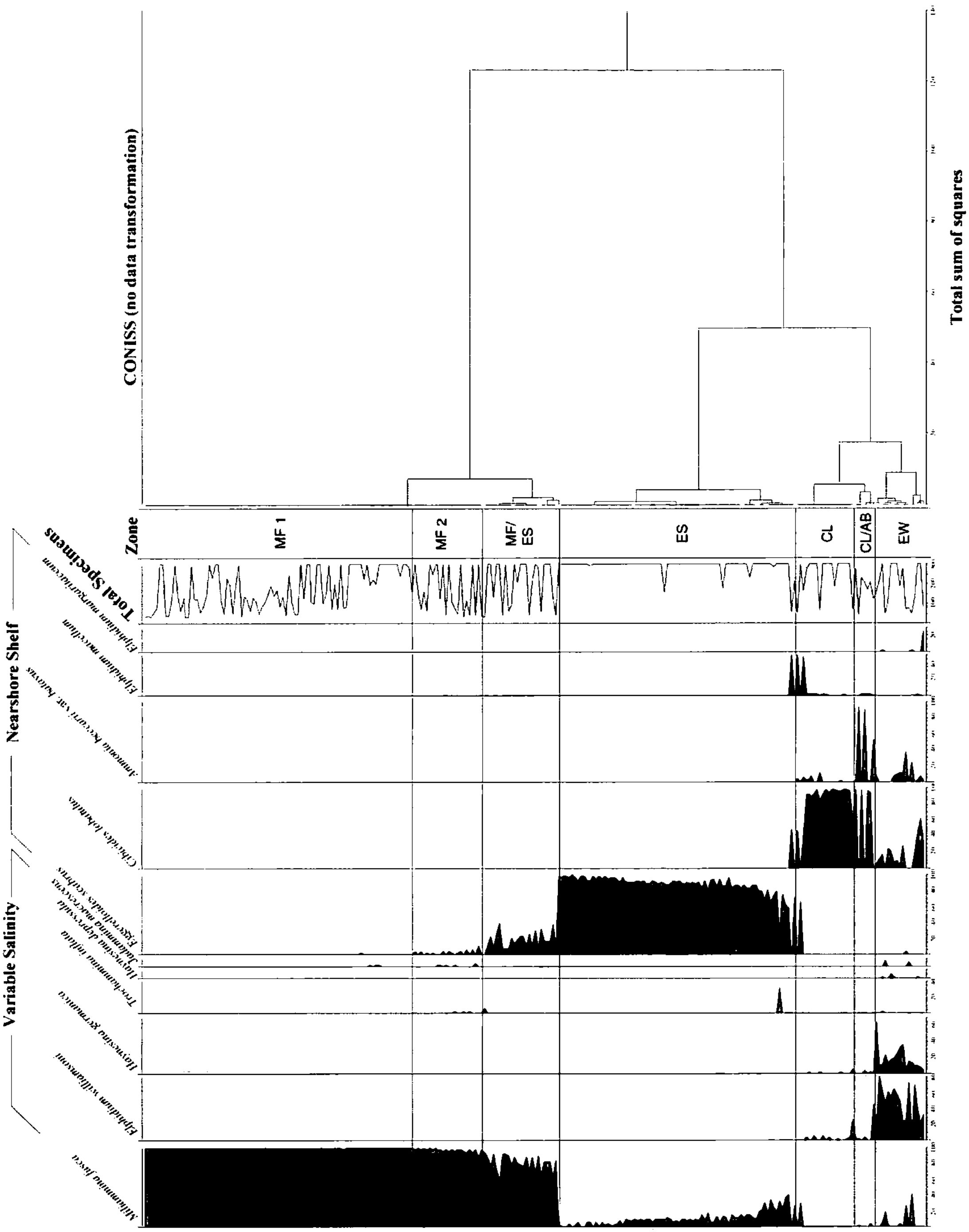


Figure 5.4.1: Total foraminiferal dataset remaining after screening of the data for statistical significance. The CONISS cluster analysis which produced the foraminiferal assemblage zones was carried out using no data transformation through the unweighted Euclidean distance method, on an unconstrained dataset.

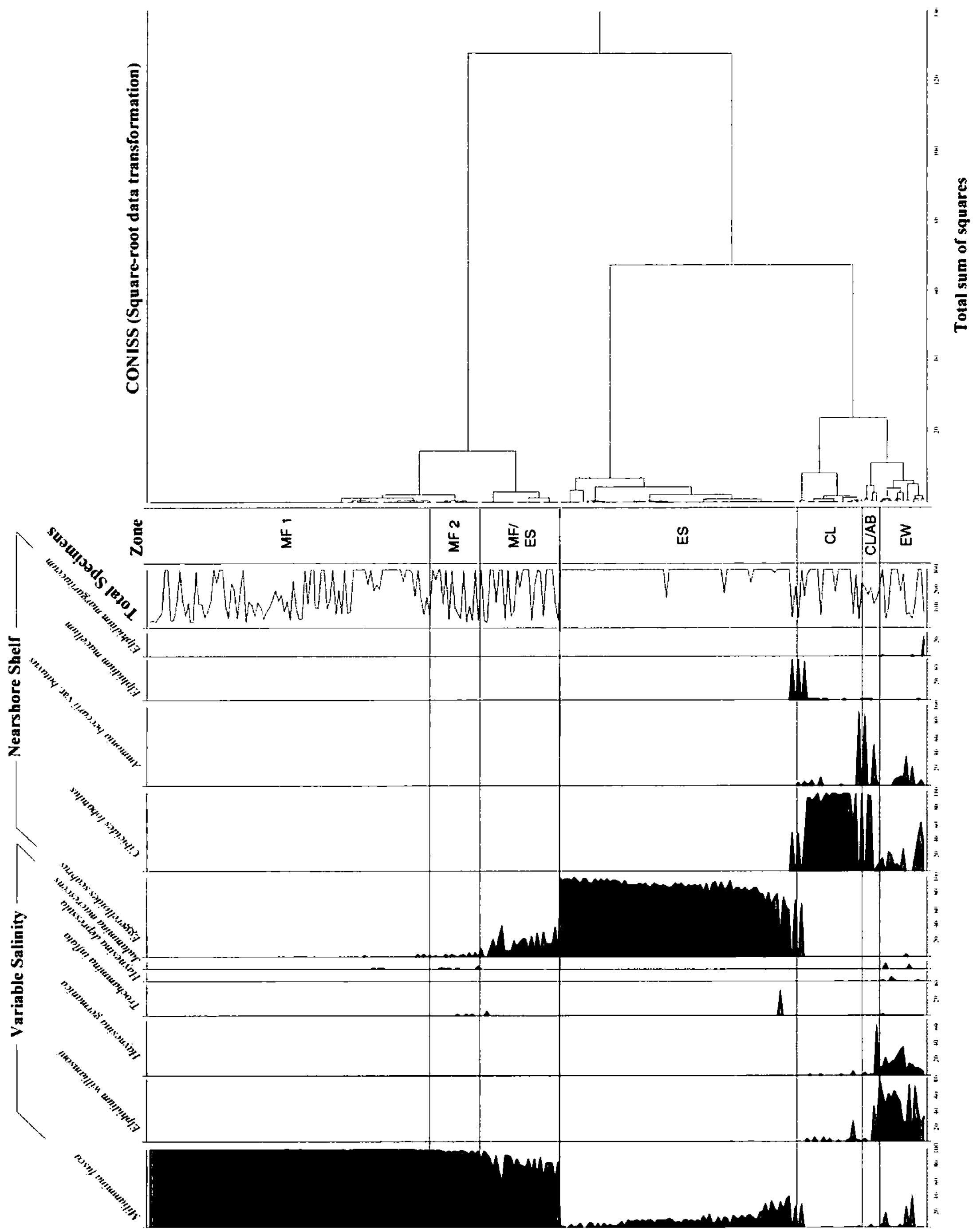


Figure 5.4.2: Total foraminiferal dataset remaining after screening of the data for statistical significance. The CONISS cluster analysis which produced the foraminiferal assemblage zones was carried out using the unweighted Chord distance method, on an unconstrained dataset, in order to give greater significance to the minor taxa.

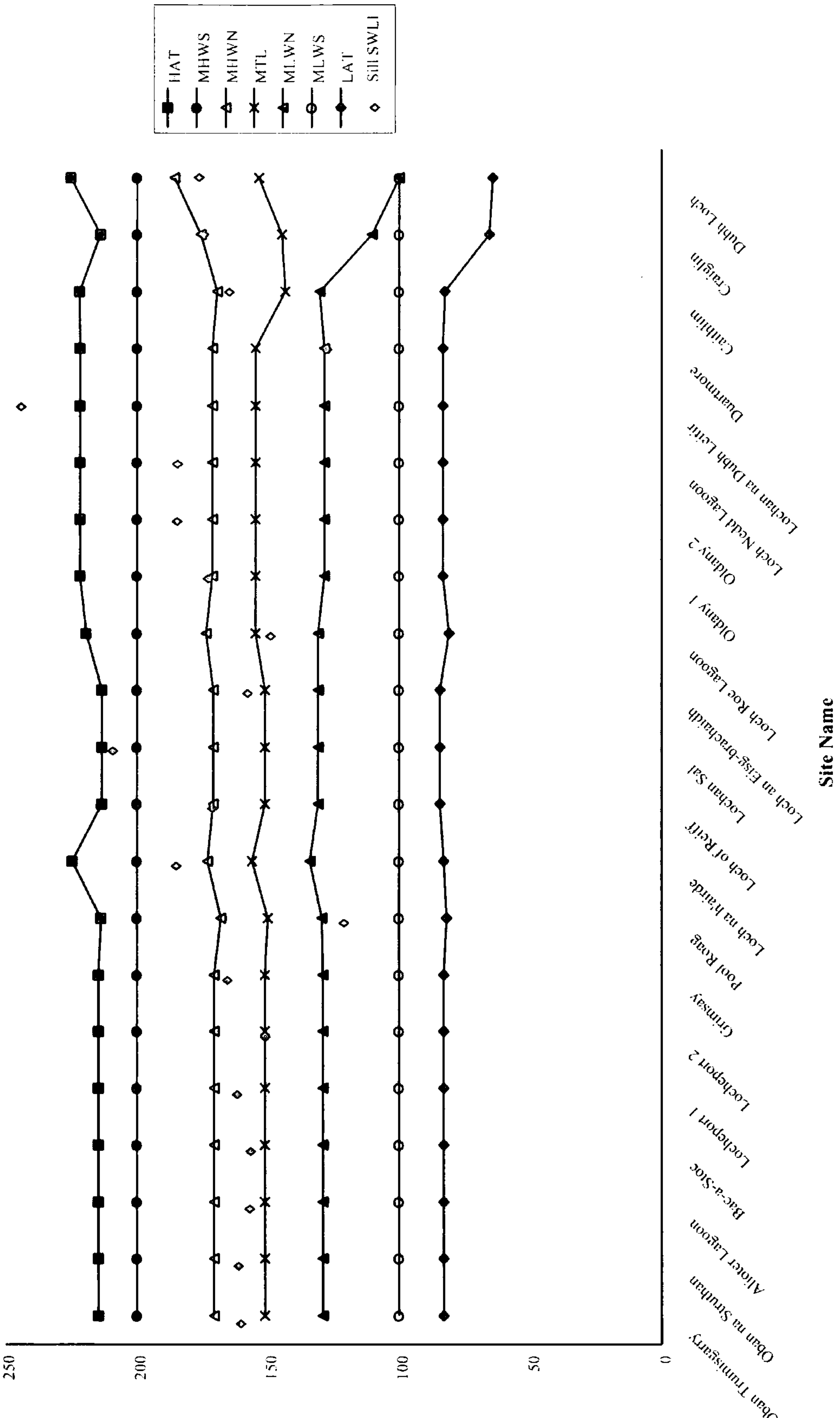


Figure 5.5: Comparisons between basin sills and constructed tide levels for all twenty sites used in this investigation using SWLI method three (equation 3).

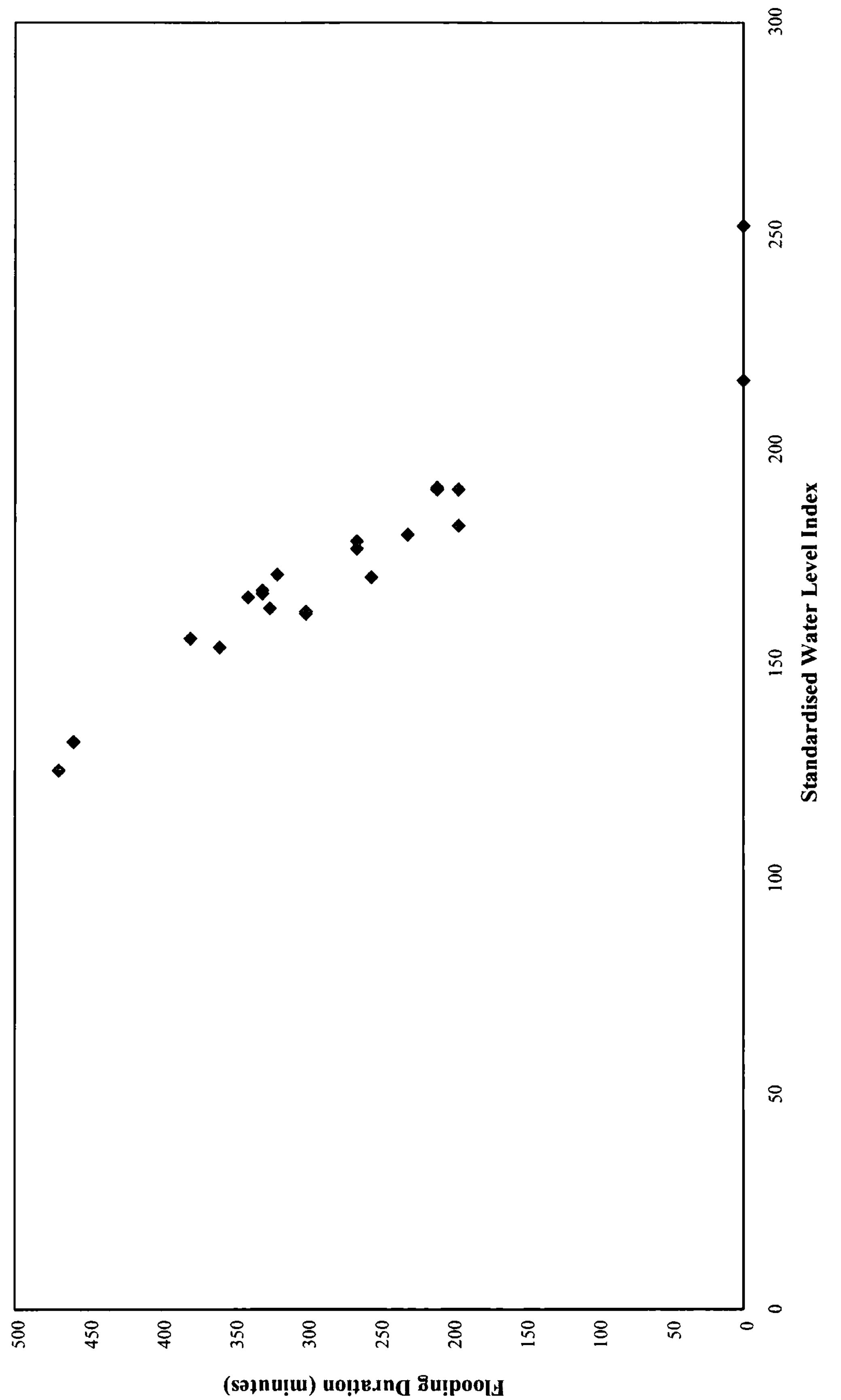


Figure 5.6: Scatter plot of SWLI, calculated using Equation 3, versus flooding frequency for all sites. The value of R^2 is 0.92.

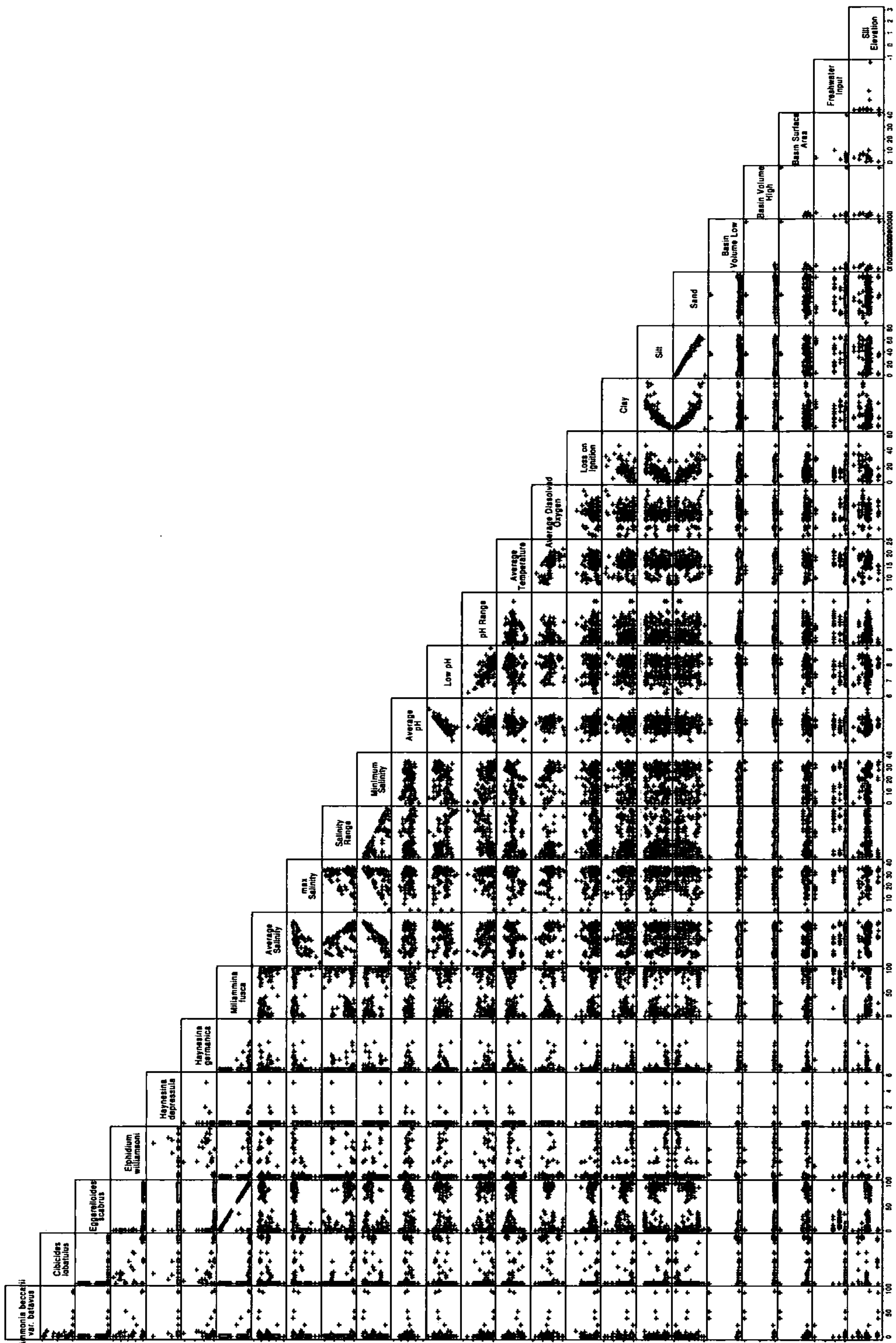


Figure 5.7: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships based on the total modern dataset.

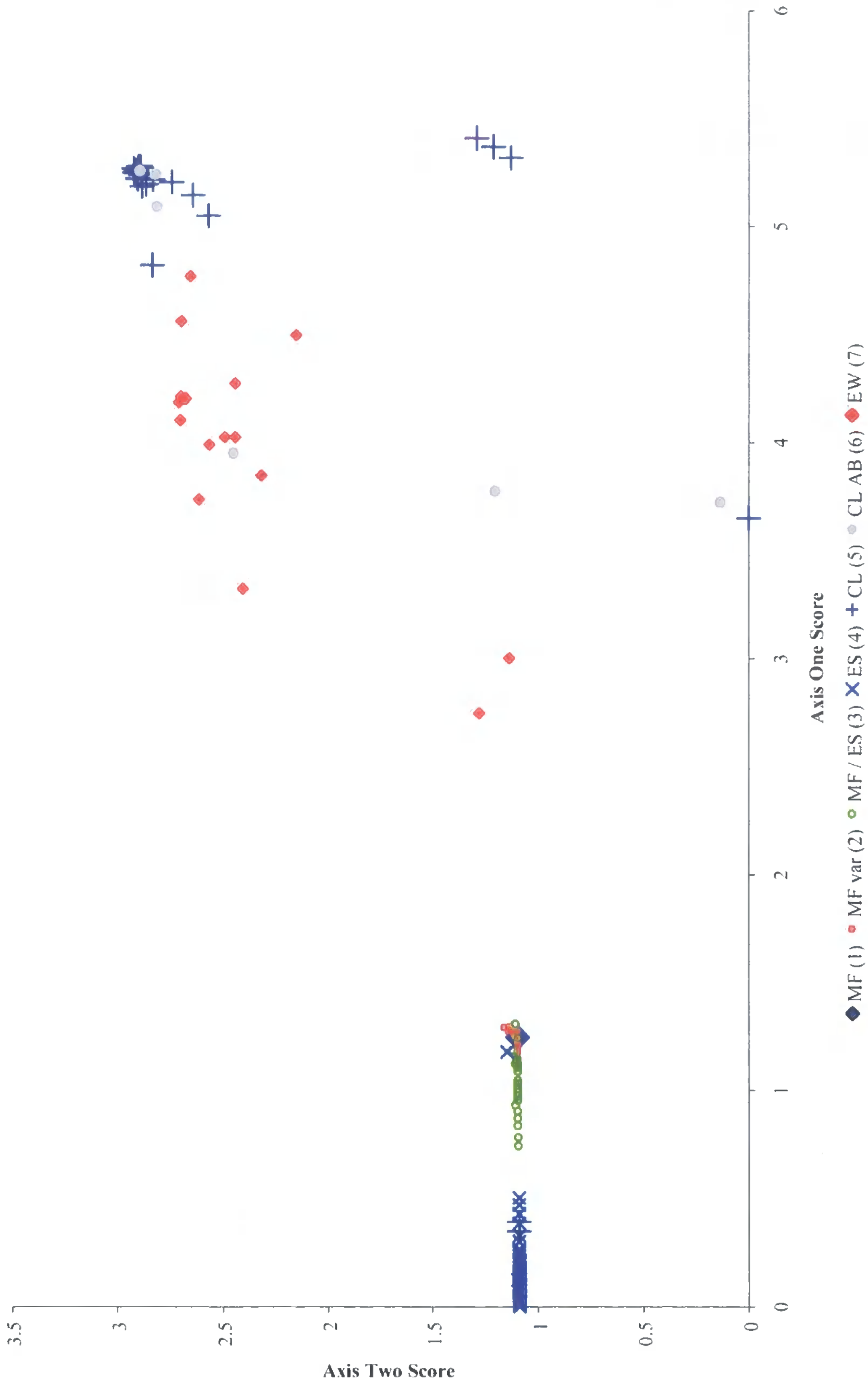


Figure 6.1: Detrended Correspondence Analysis (DCA) of the total foraminiferal dataset. The data is split into the seven zones identified by unconstrained Euclidean distance and Chord distance cluster analysis. All samples from the MF 1 cluster are plotted in the same position because the zone is 100 % Miliammina fusca; all samples in this zone therefore have identical Eigenvalues.

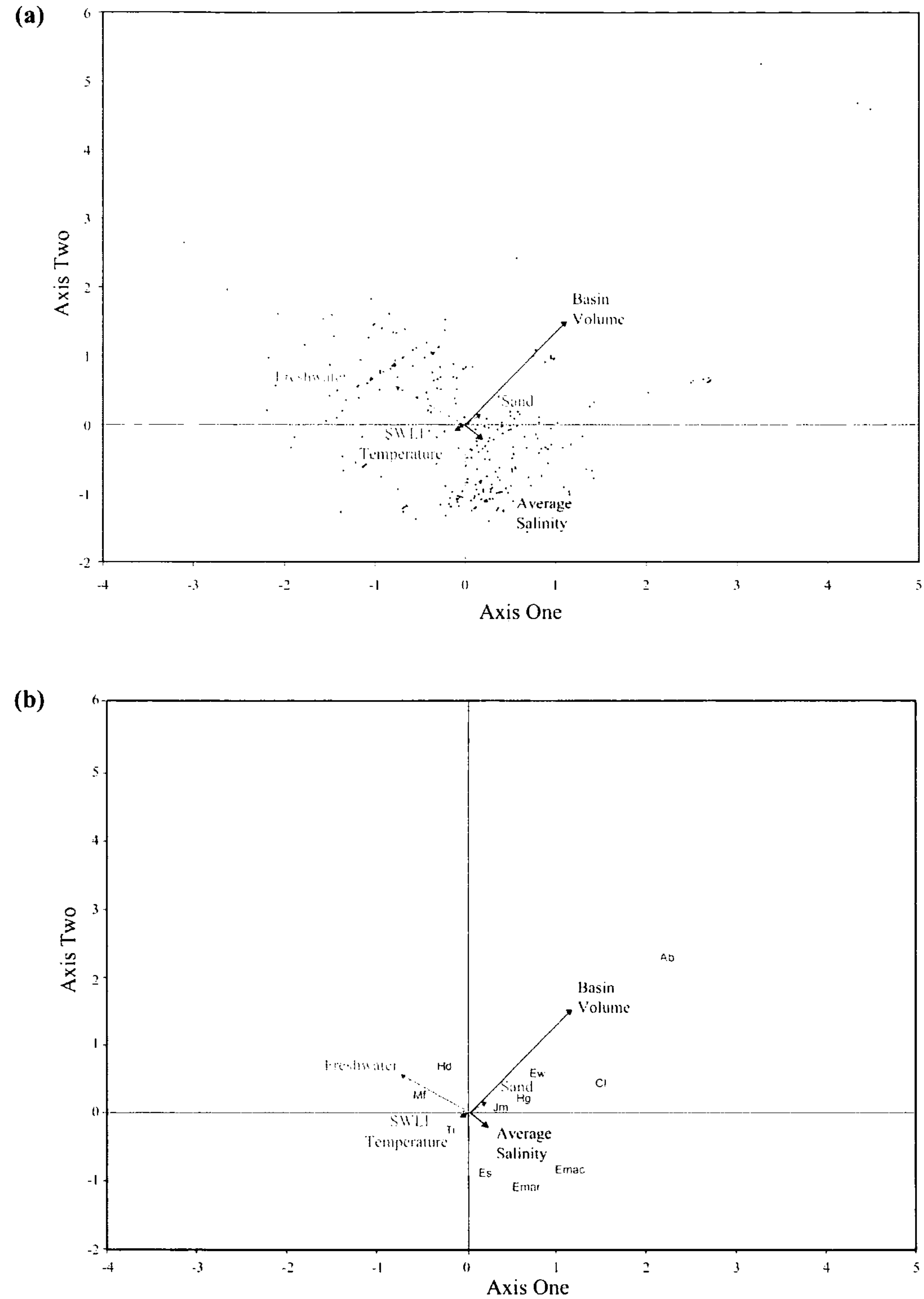


Figure 6.2: CCA Biplots for a) Sample – environment and b) Species – environment. Mf = *Miliammina fusca*, Hd = *Haynesina depressula*, Ti = *Trochammina inflata*, Es = *Eggerelloides scabrus*, Emar = *Elphidium margaritaceum*, Emac = *Elphidium macellum*, Jm = *Jadammina macrescens*, Hg = *Haynesina germanica*, Ew = *Elphidium williamsoni*, Cl = *Cibicides lobatulus*, and Ab = *Ammonia beccarii* var. *batavus*.

The six labelled environmental gradients are plotted as vectors, with the length of the arrow proportional to the degree of influence over the biological assemblage and the direction of the arrow being the direction of maximum change of that environmental variable within the samples / species.

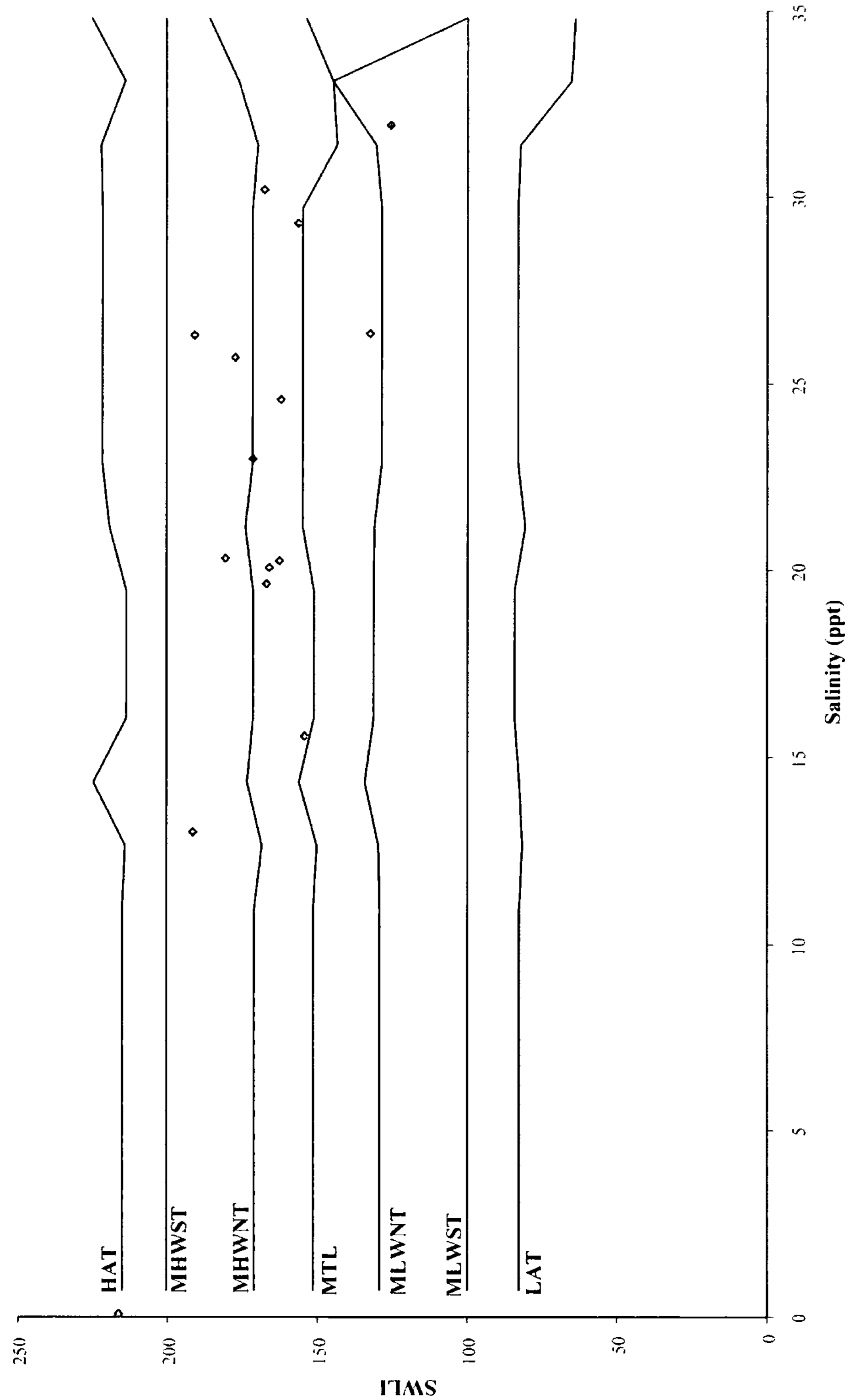


Figure 6.3: The relationship between the position of a basin sill in the tidal cycle, and the average salinity within that basin, for the 15 sites included in the modern training set. Although the lowest salinity is found in the basin with its sill at the highest position in the tidal cycle, and *vice versa*, the overall pattern is not clear-cut, suggesting that the relationship between the two factors is not straightforward; other variables must interact to complicate the connection between salinity and the position of the sill in the tidal cycle.

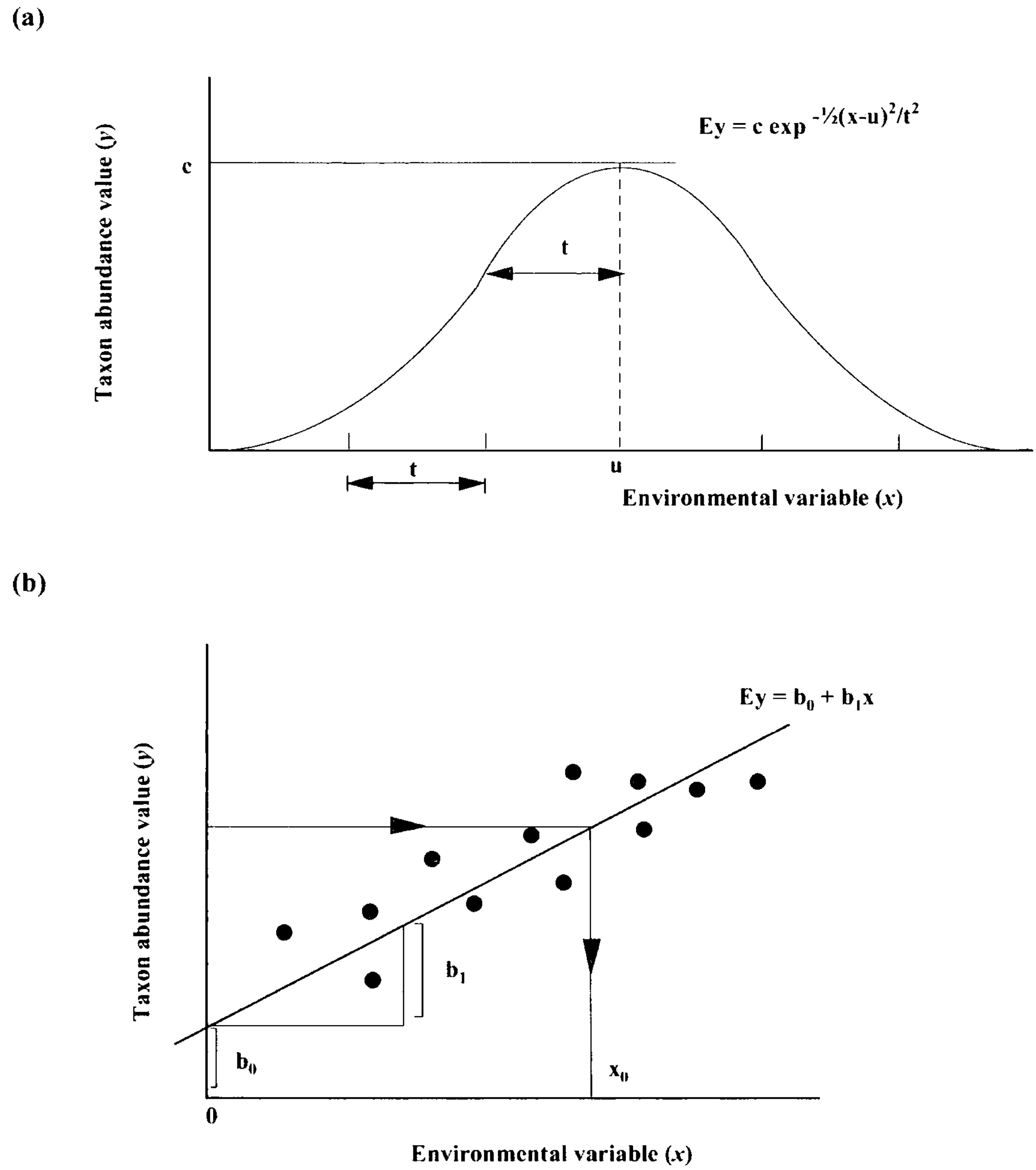


Figure 6.4: Taxon-environment response models. a) Gaussian unimodal relationship between the abundance (*y*) of a taxon and an environmental variable (*x*). The three important ecological parameters of the model are shown; u = optimum, t = tolerance, c = maximum. The equation for the expected value of the taxon's abundance *y* is given for the Gaussian response model (modified from ter Braak, 1988).

b) Linear relationship between the abundance (*y*) of a taxon and an environmental variable (*x*). The equation for the expected value of the taxon's abundance *y* in relation to *x* is given for the linear response model (b_0 = intercept, b_1 = slope or regression coefficient (modified from ter Braak, 1988; after Birks, 1995).

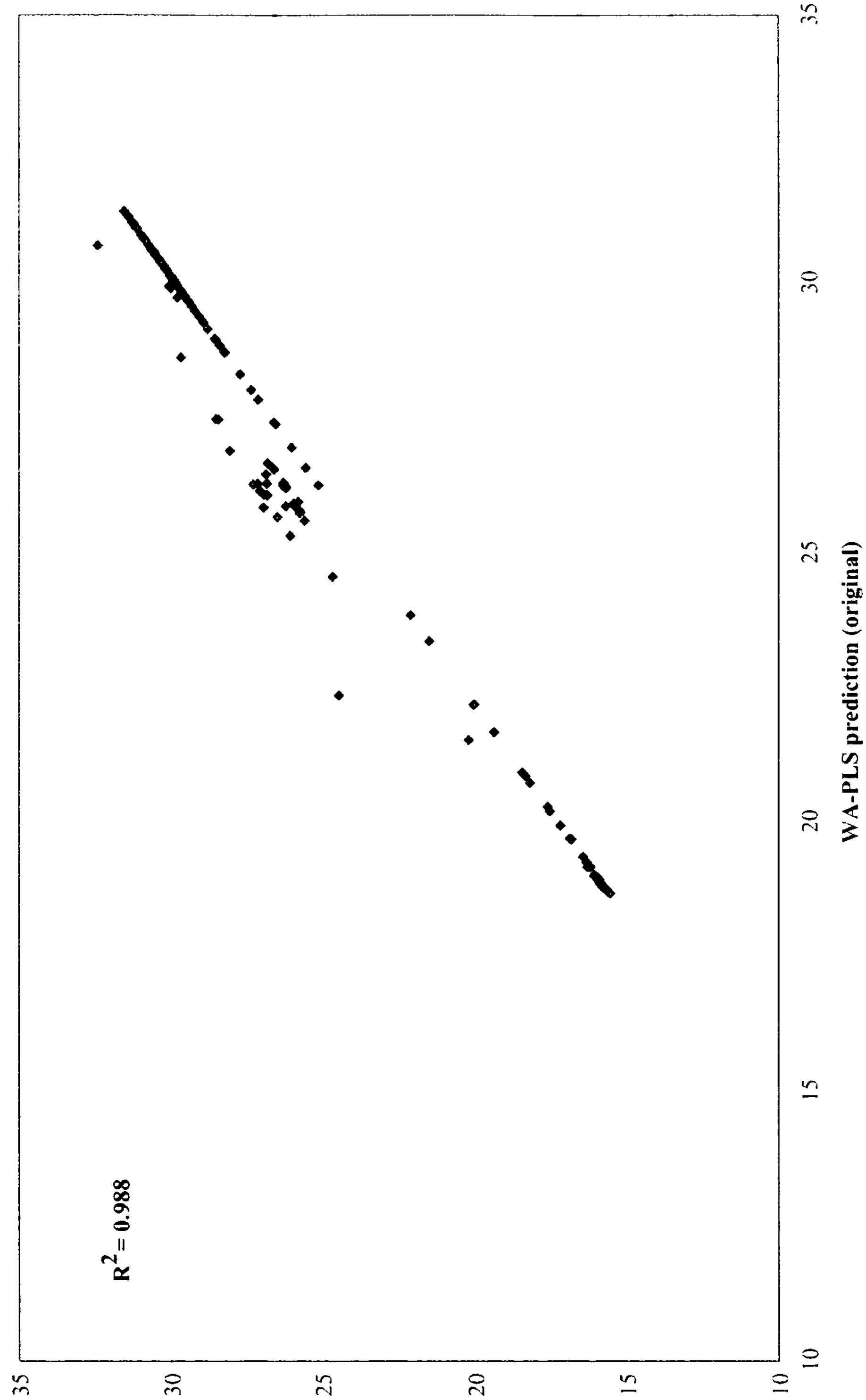


Figure 6.5: WA-PLS coefficients predicted for the 194 samples in the screened data-set. The X-axis shows the value of average salinity (‰) predicted when the original modern training set (266 samples) is used to develop the transfer function, plotted against the revised prediction produced by the transfer function when using the screened data-set of 194 samples.

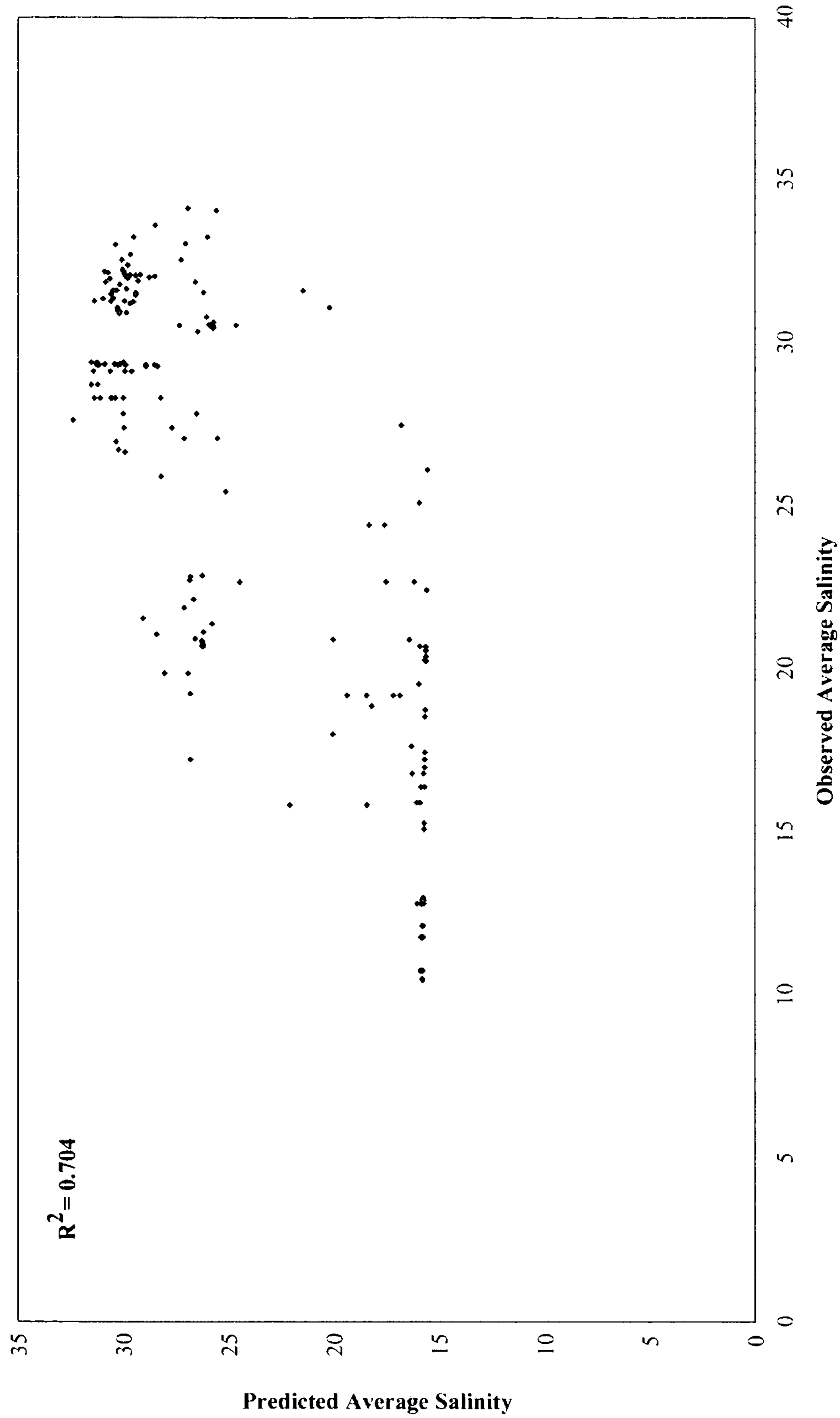


Figure 6.6: Observed average salinity versus WA-PLS predicted average salinity for the screened modern training set.

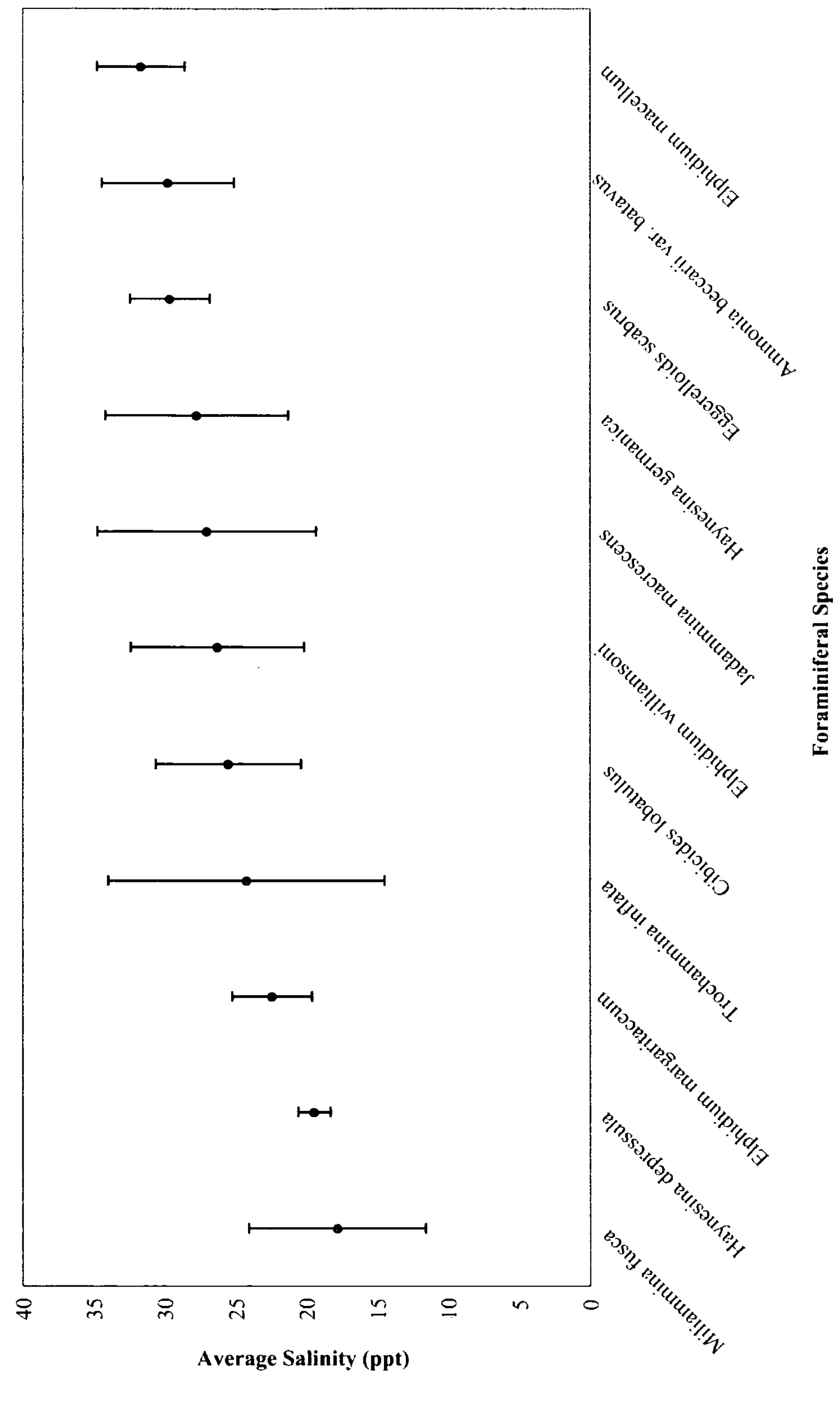


Figure 6.7: Optimum (weighted mean) average salinity for each of the eleven species in the screened modern training set, using inverse Weighted Averaging (WA). Tolerance (standard deviation) levels are indicated by the error bars.

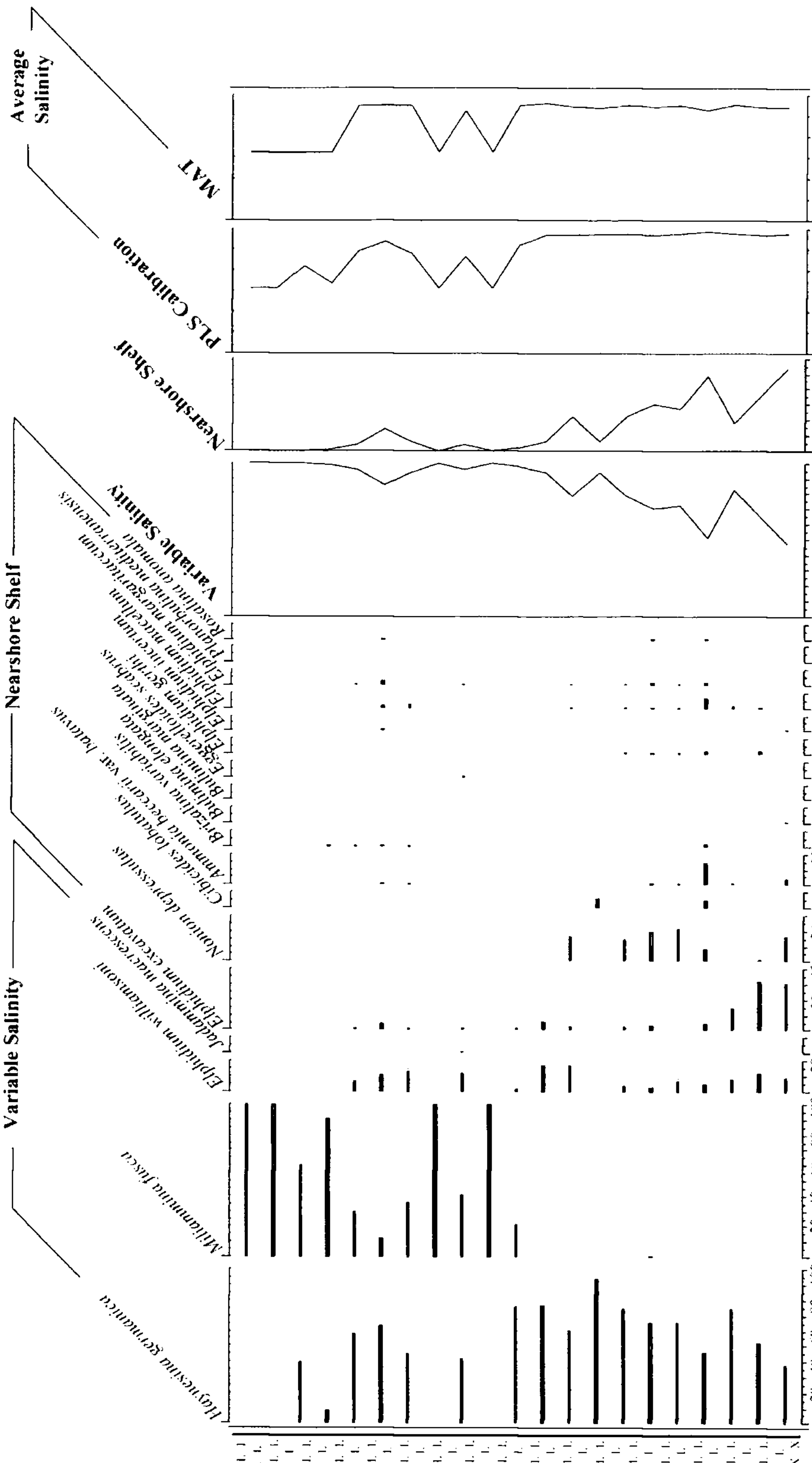


Figure 6.8: Foraminiferal assemblage from a fossil core from Rumach VI basin, Arisaig, Scotland, together with predicted average salinity values calculated by partial-least-squares (PLS) calibration and Modern Analogue Technique (MAT). Lithology is modified from Troels-Smith (1955): L L L = silt and clay; X X X = bedrock.

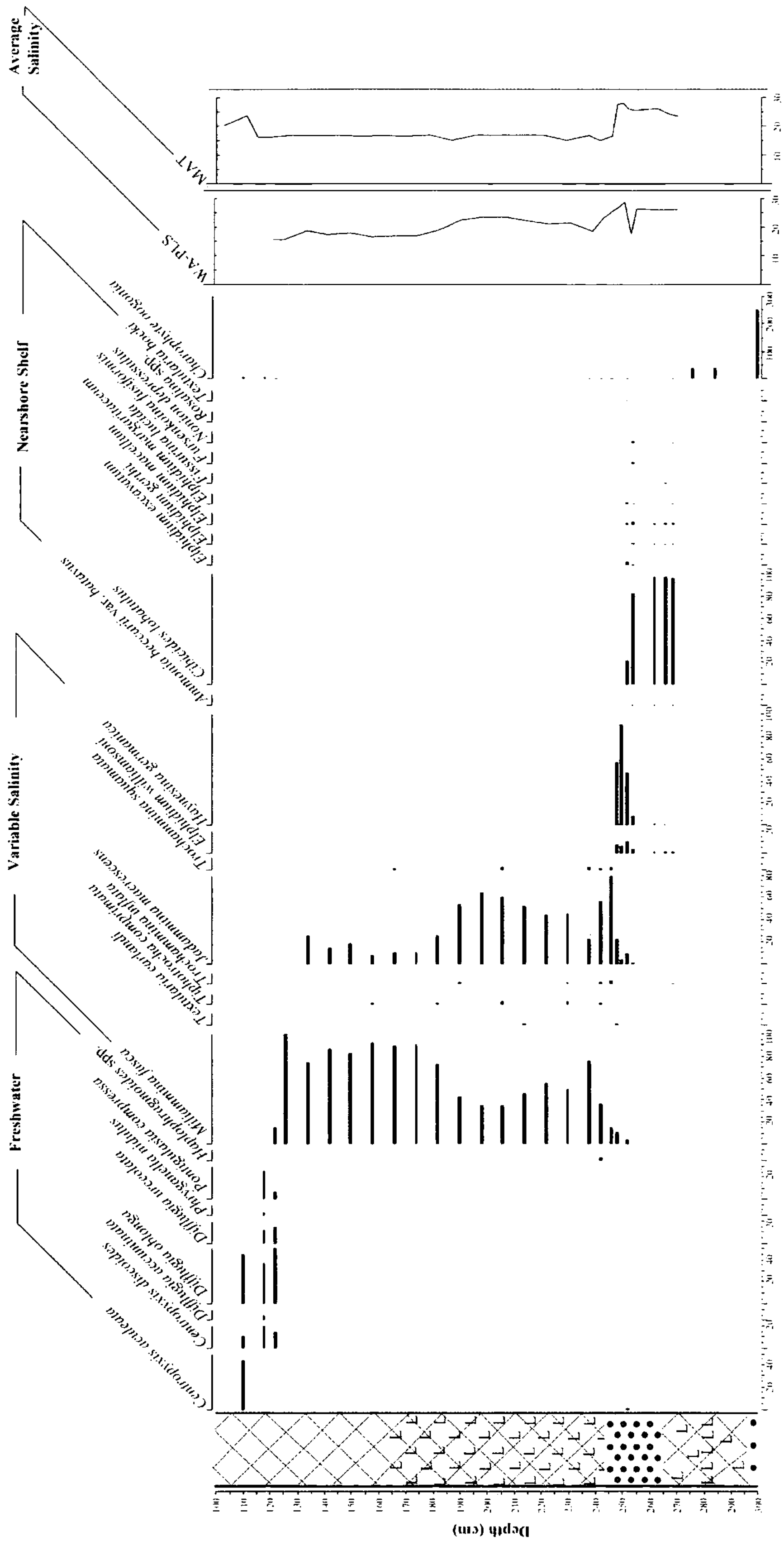


Figure 6.9: Foraminiferal assemblage from a fossil core from Dubh Lochan basin, Coigach, Scotland (after Shennan *et al.*, 2000), together with predicted average salinity values calculated by partial-least-squares (PLS) calibration and Modern Analogue Technique (MAT). Lithology is modified from Troels-Smith (1955): cross-hatching = organic limus; L L L = silt and clay; ˙˙˙ = sand.

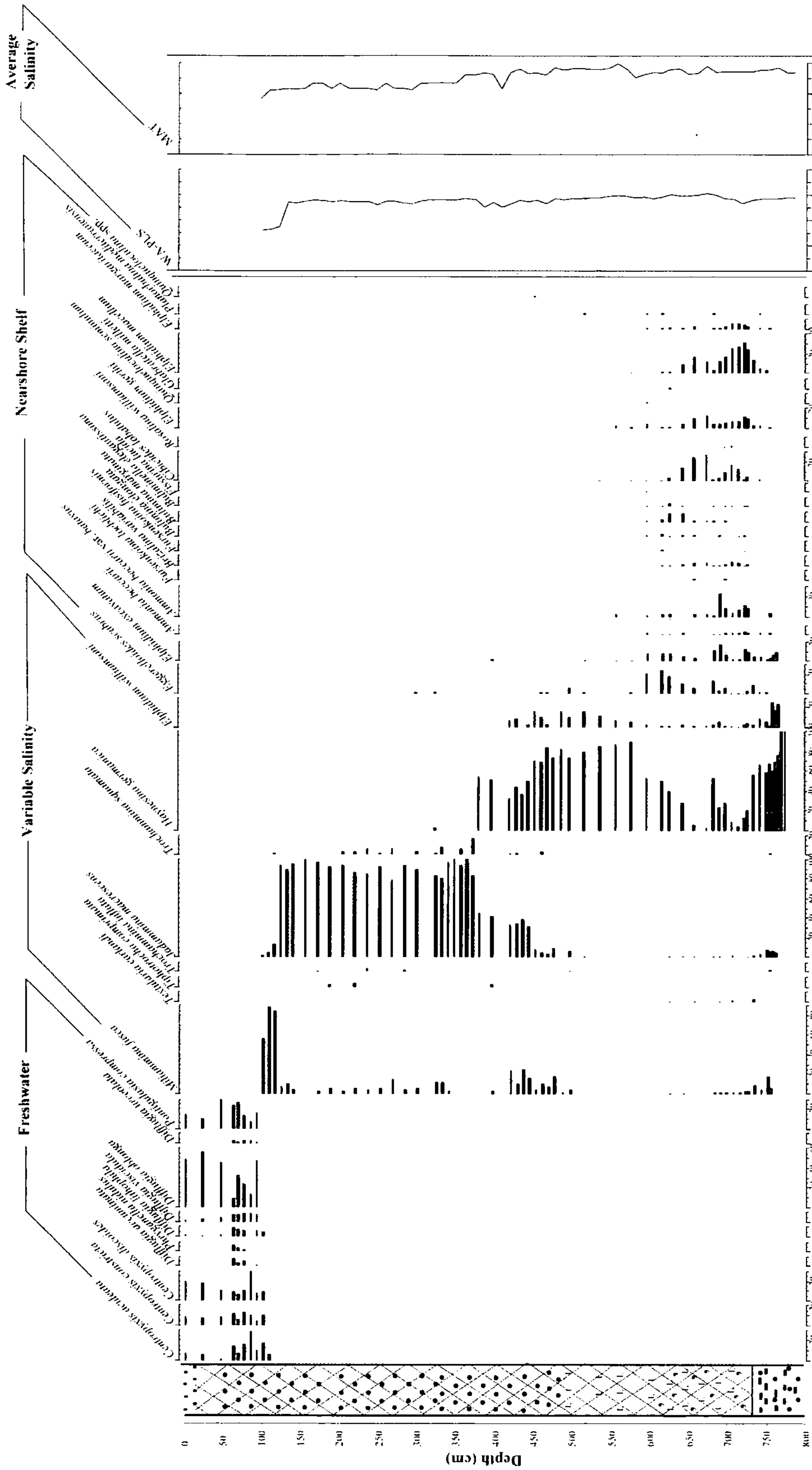


Figure 6.10: High-resolution fossil foraminiferal and thecamoebian record from Loch nan Corr, Kintail (after Lloyd, 2000). Lithology is modified from Troels-Smith (1955): cross-hatching = organic limus; L L L = silt and clay; ˙˙˙ = sand; | | | = turfa peat; - - - = well-humified organic material; , = shells.

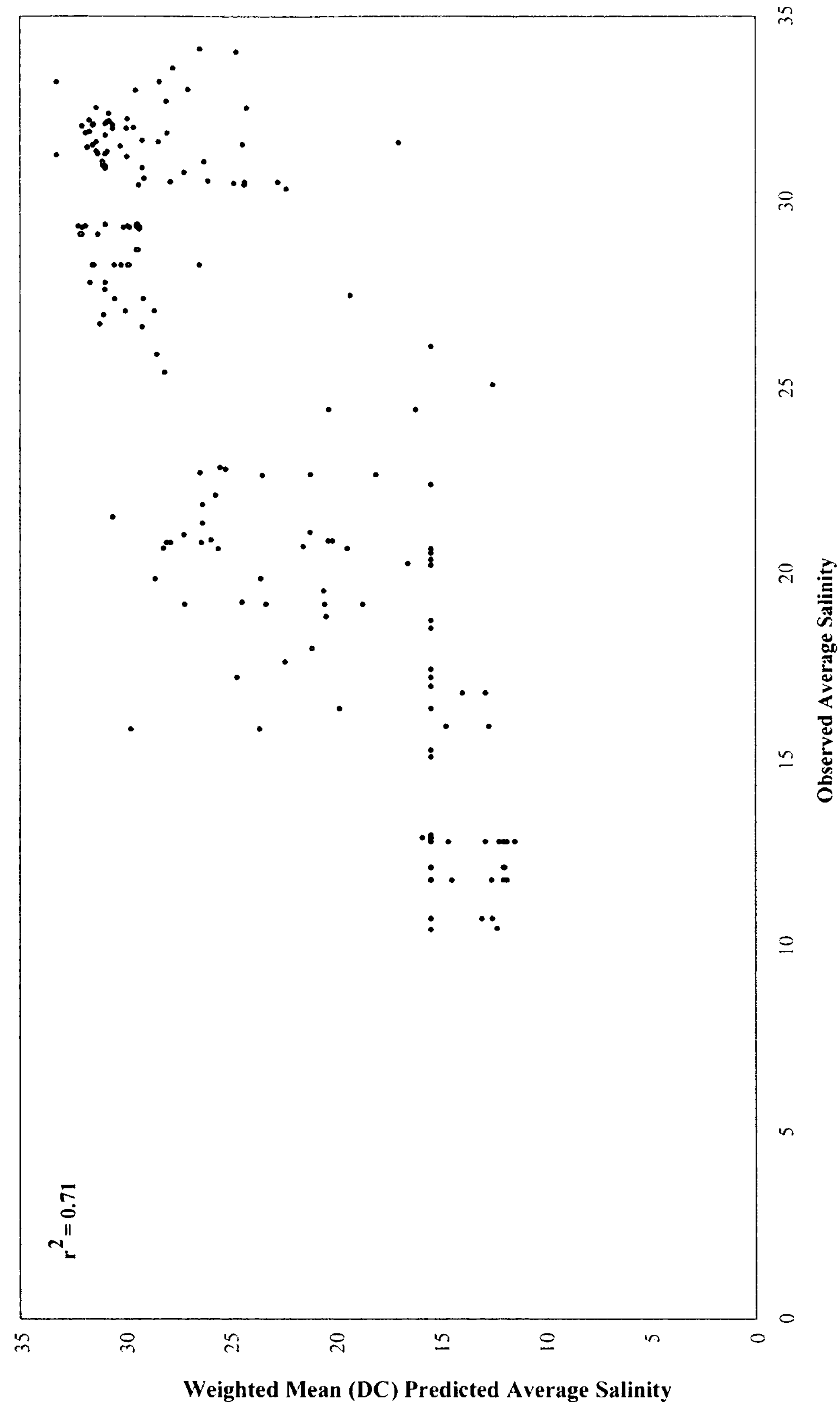


Figure 6.11: Observed versus MAT predicted average salinity values for the screened modern training set.

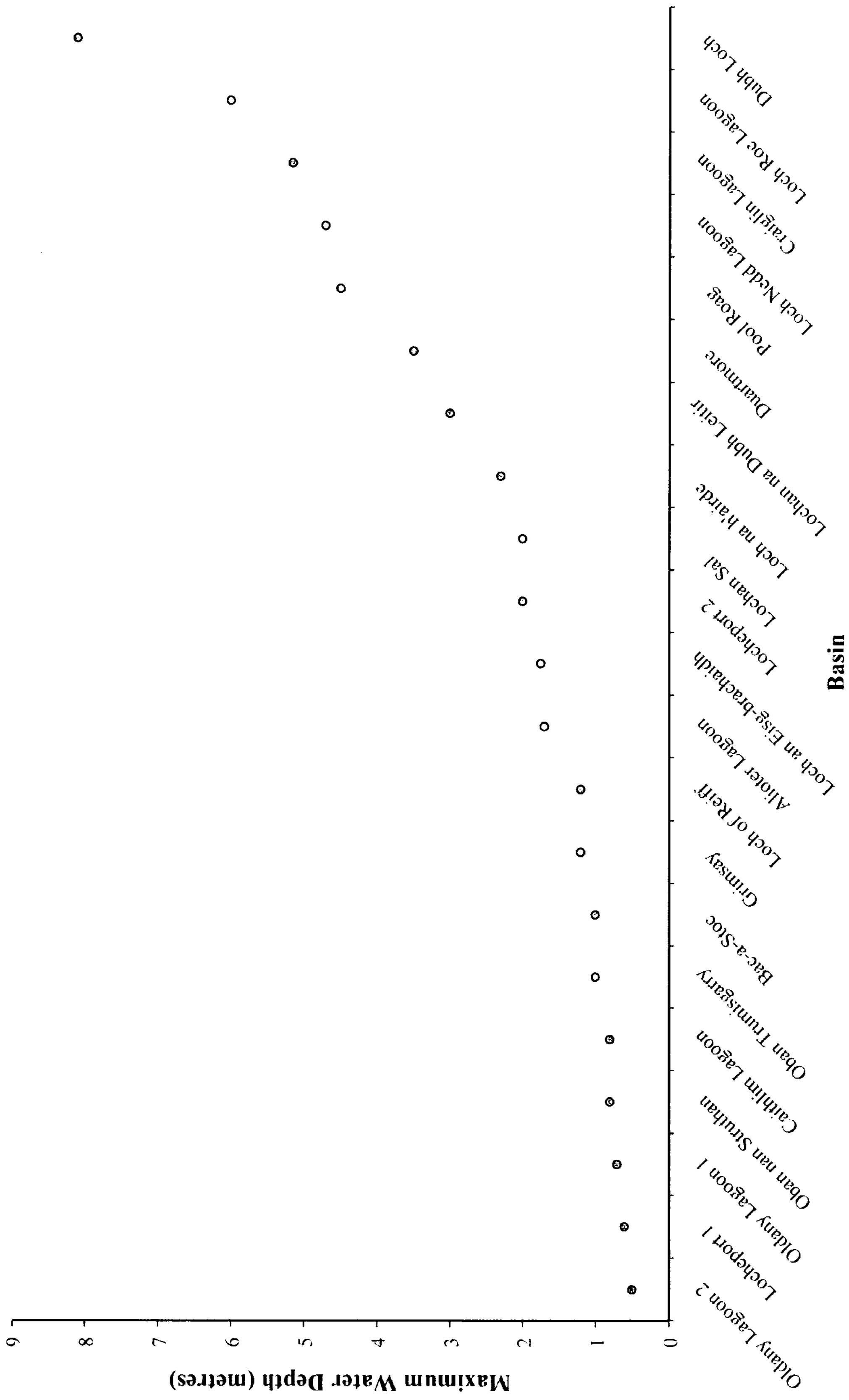


Figure 7.1: Maximum water depth at MHWST in the modern isolation basins sampled. The majority are considerably shallower than the fossil basins during the fully marine or nearshore shelf stage.

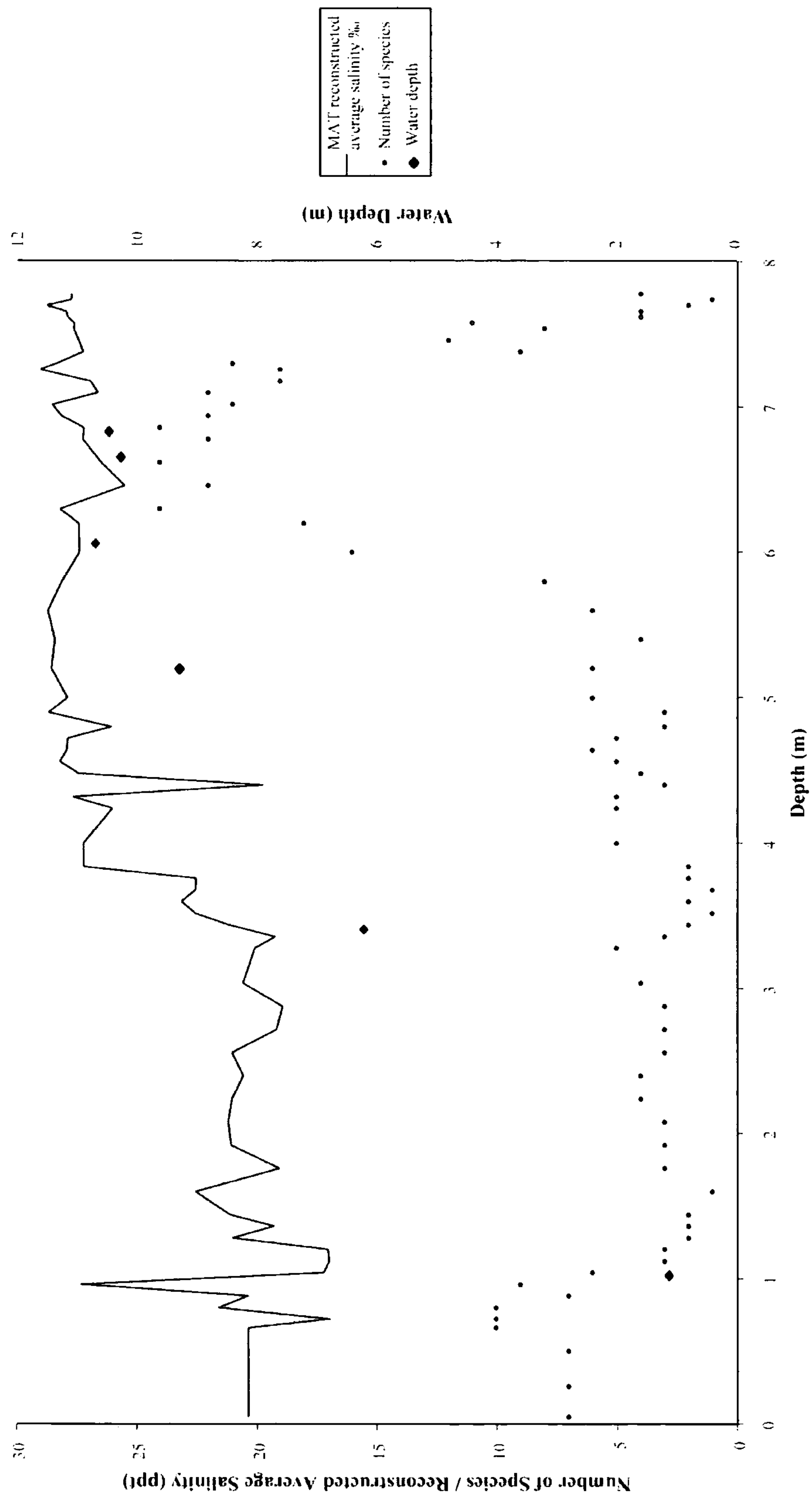


Figure 7.2: MAT reconstructed average salinity, water depth and foraminiferal species diversity versus depth for Loch nan Corr, Kintail. The graph of species diversity shows a general trend of increasing species diversity with increasing water depth (the species diversity between 5 and 100 cm depth is for thecamoebians). Maximum species diversity occurs in the nearshore shelf (fully marine) stage (600 – 726 cm).

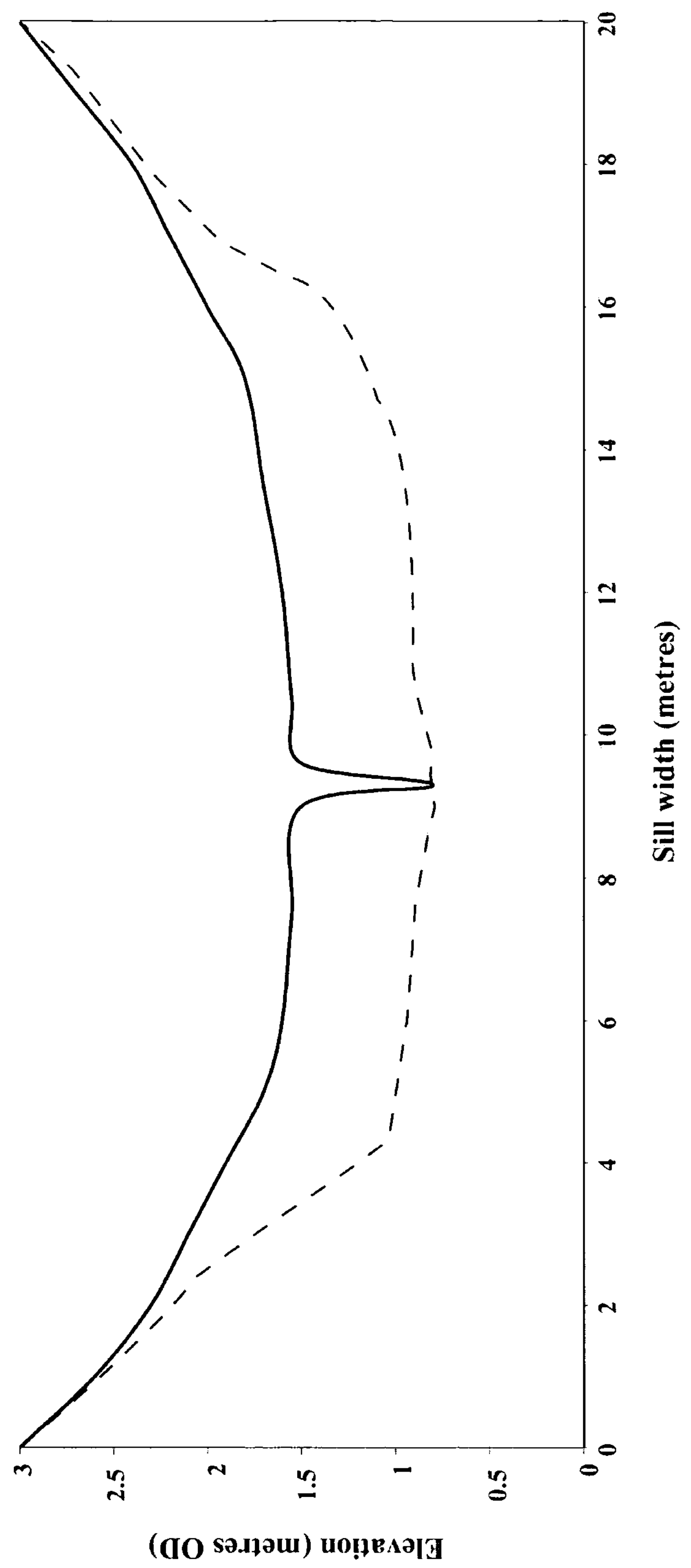


Figure 7.3: Potential errors in measuring only the minimum sill elevation. The marine input over the sill indicated by the dashed line will be considerably greater than that over the sill indicated by the solid line, yet both have the same minimum sill elevation. For this reason, an approximate measure of marine input is suggested.

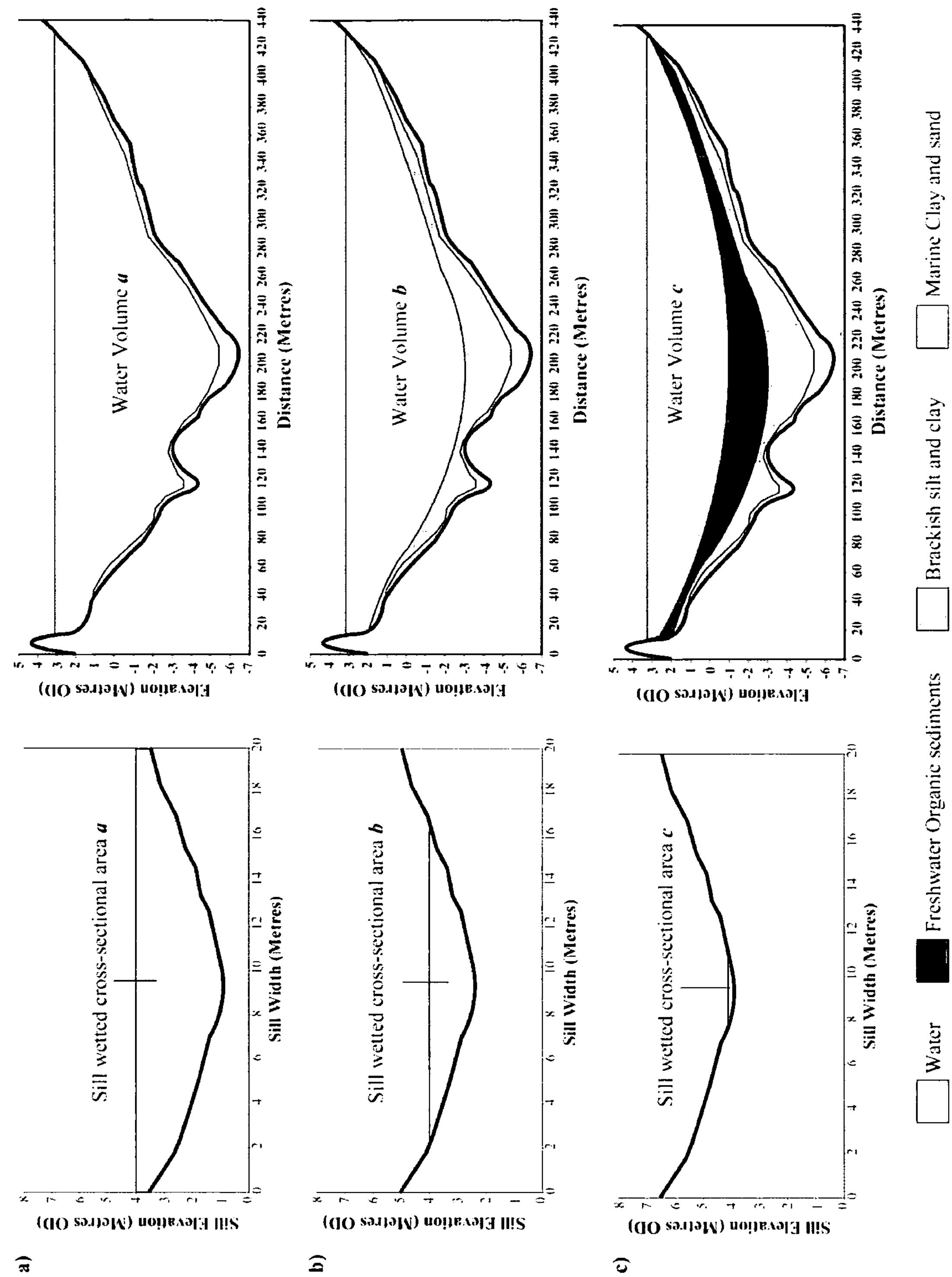


Figure 7.4: Changes in the estimated marine input – basin volume ratio during the isolation process. a) indicates fully marine conditions with marine sedimentation, with the wetted sill cross-sectional area *a* and basin water volume *a* at MHWST. b) indicates brackish or variable salinity conditions with associated sedimentation, with the wetted sill cross-sectional area *b* and basin water volume *b* at MHWST. c) indicates freshwater conditions with associated sedimentation, with the wetted sill cross-sectional area *c* and basin water volume *c* at MHWST. This ratio will control the salinity of the basin, with the basin water volume controlling the inertia within the system to changes such as isolation and freshwater input.

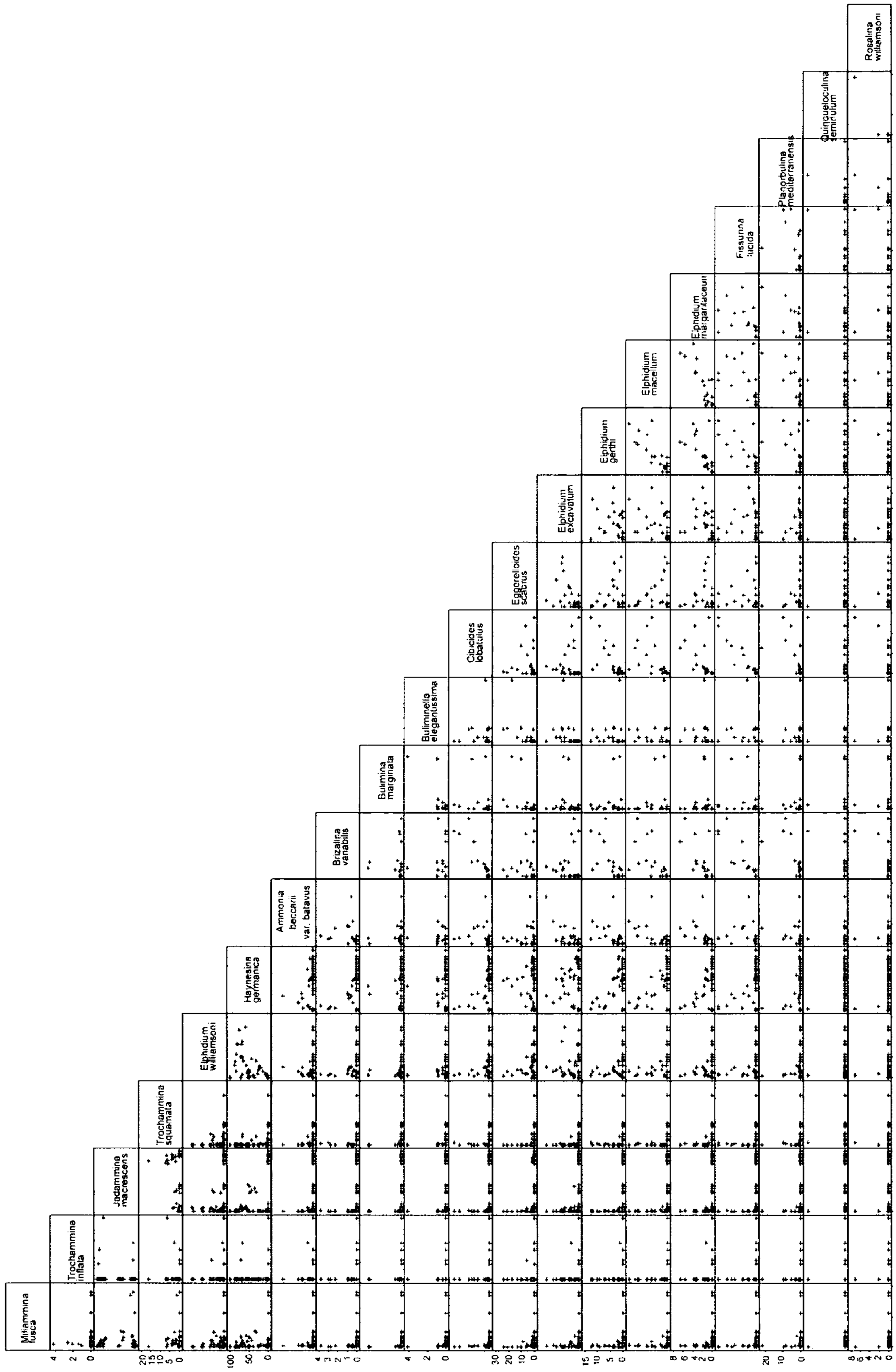


Figure 7.5: Foraminifera – foraminifera relationships in the fossil isolation basin Loch nan Corr, Kintail.

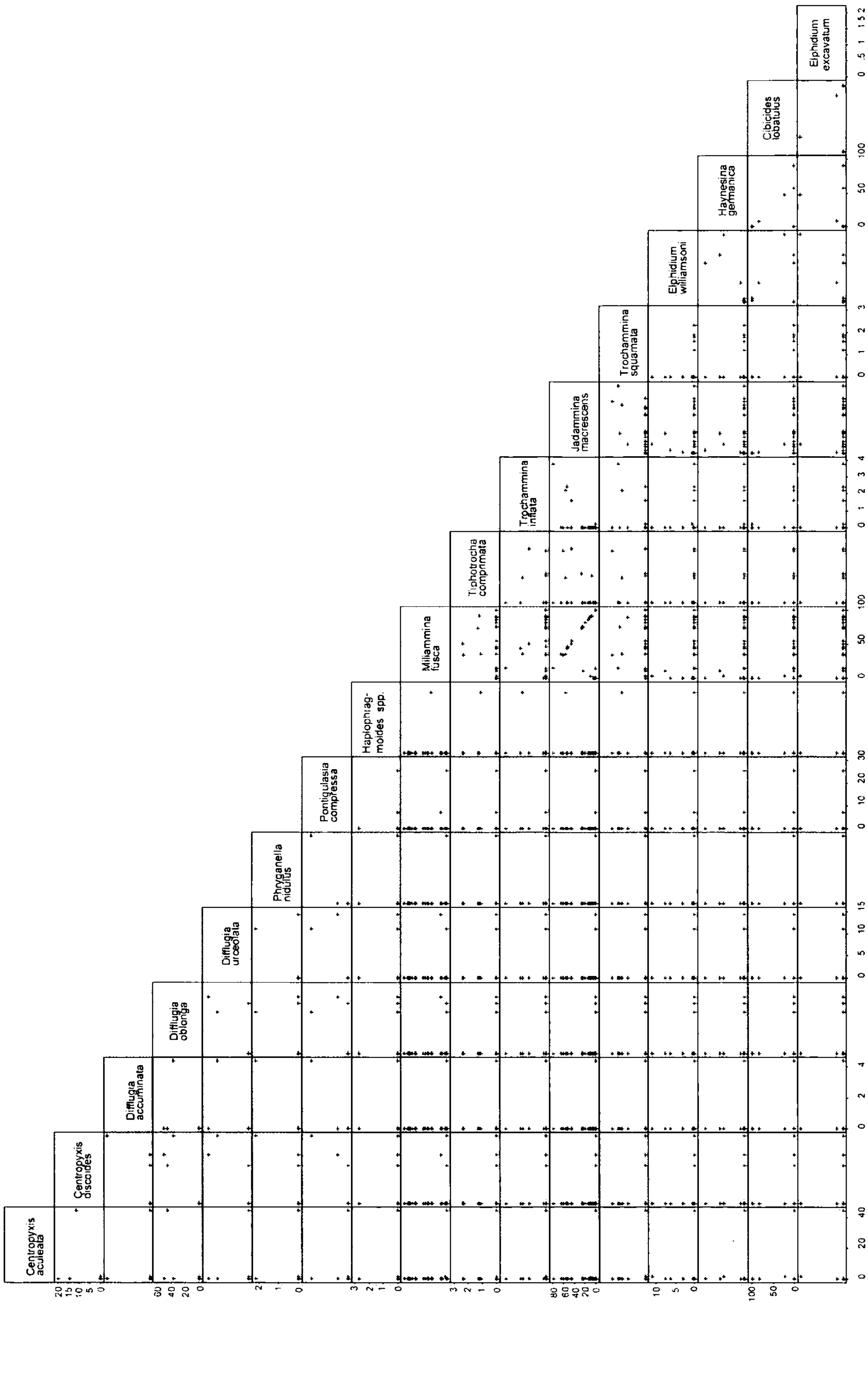


Figure 7.6: Foraminifera – foraminifera relationships in the fossil isolation basin Dubh Lochan, Coigach.

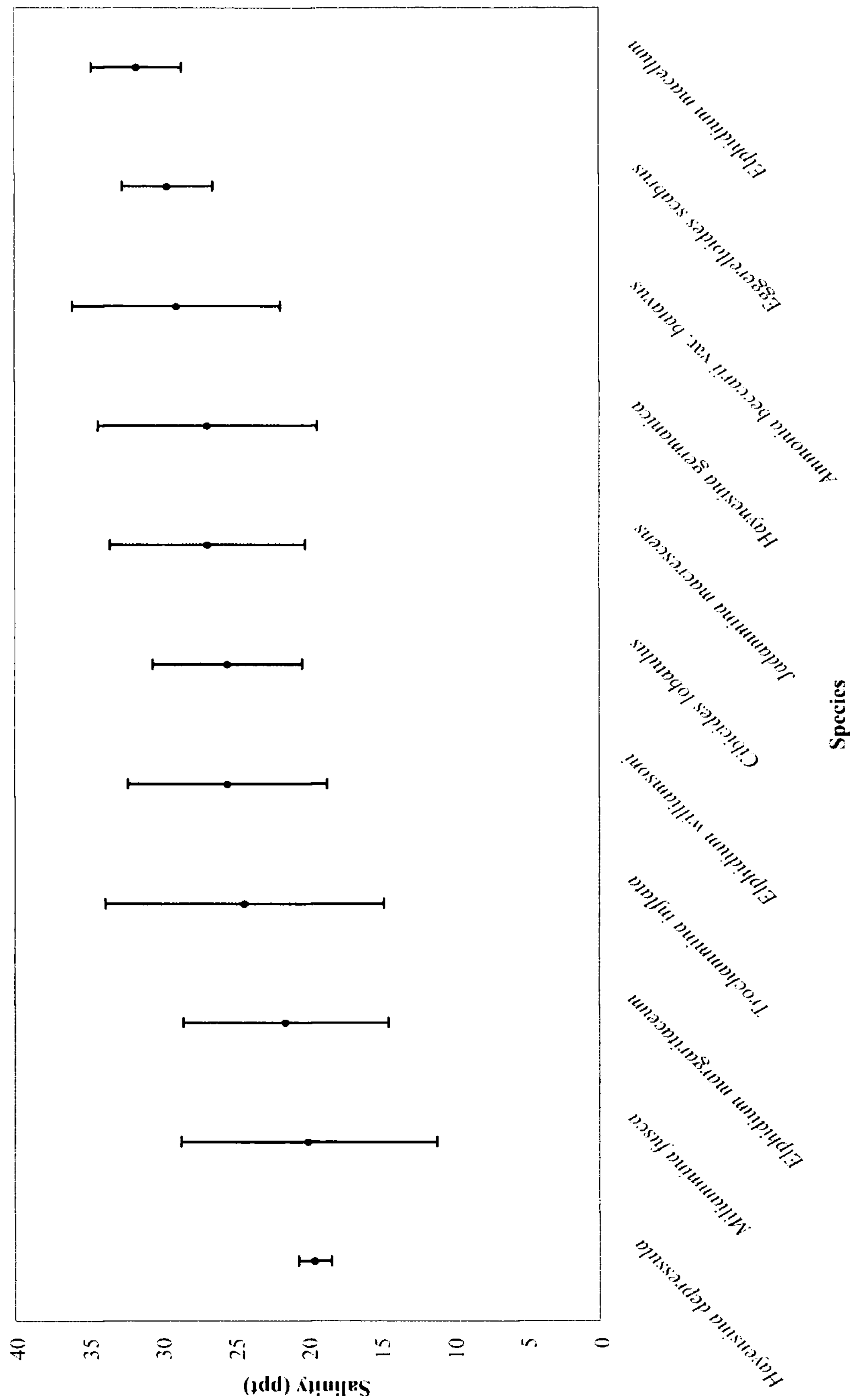


Figure 7.7: Optimum (weighted mean) average salinity (‰) for each of the eleven species in the screened modern training set, using inverse Weighted Averaging (WA). Tolerance (standard deviation) levels are indicated by the error bars.

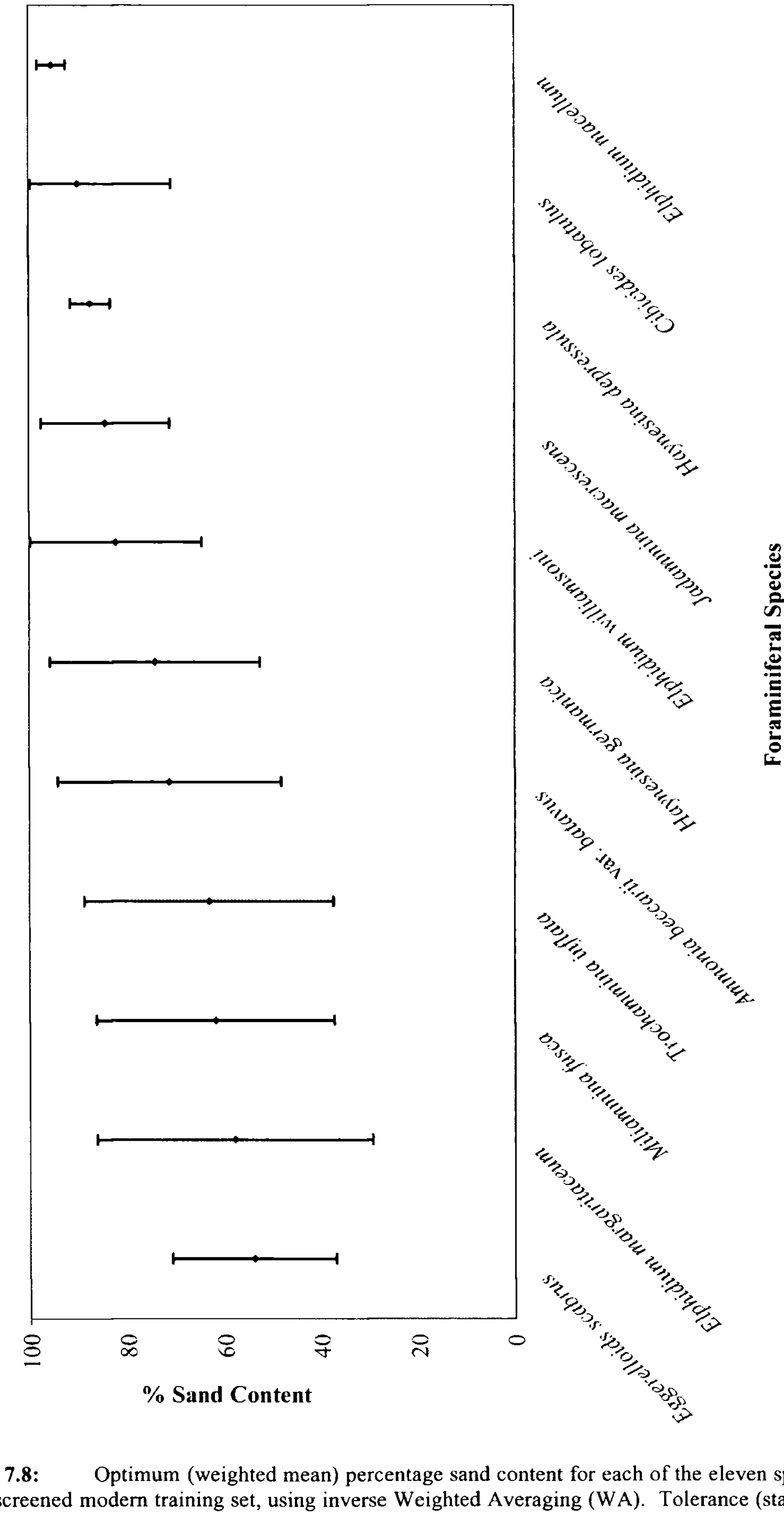


Figure 7.8: Optimum (weighted mean) percentage sand content for each of the eleven species in the screened modern training set, using inverse Weighted Averaging (WA). Tolerance (standard deviation) levels are indicated by the error bars.

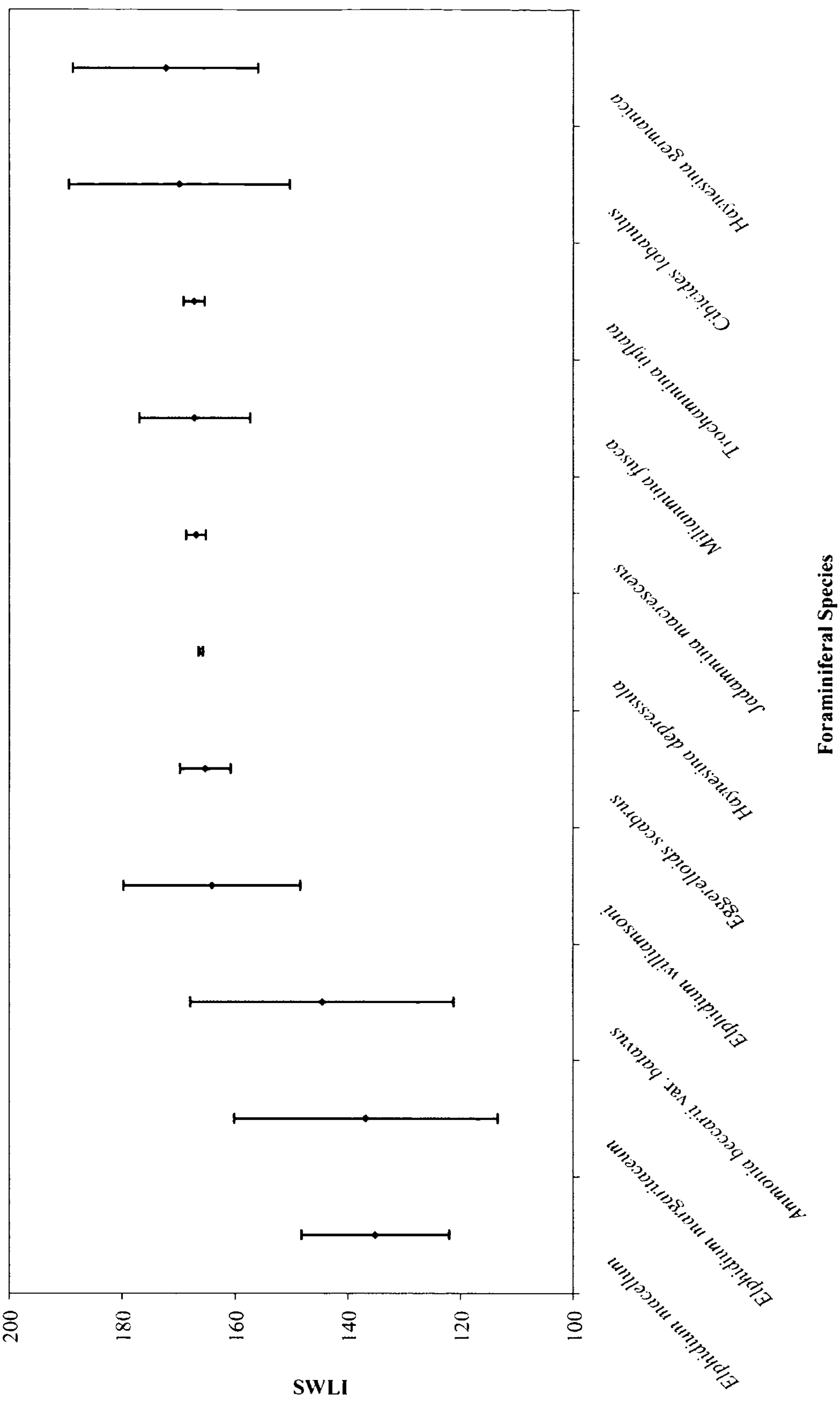


Figure 7.9: Optimum (weighted mean) Standardised Water Level Index (SWLI) for each of the eleven species in the screened modern training set, using inverse Weighted Averaging (WA). Tolerance (standard deviation) levels are indicated by the error bars.

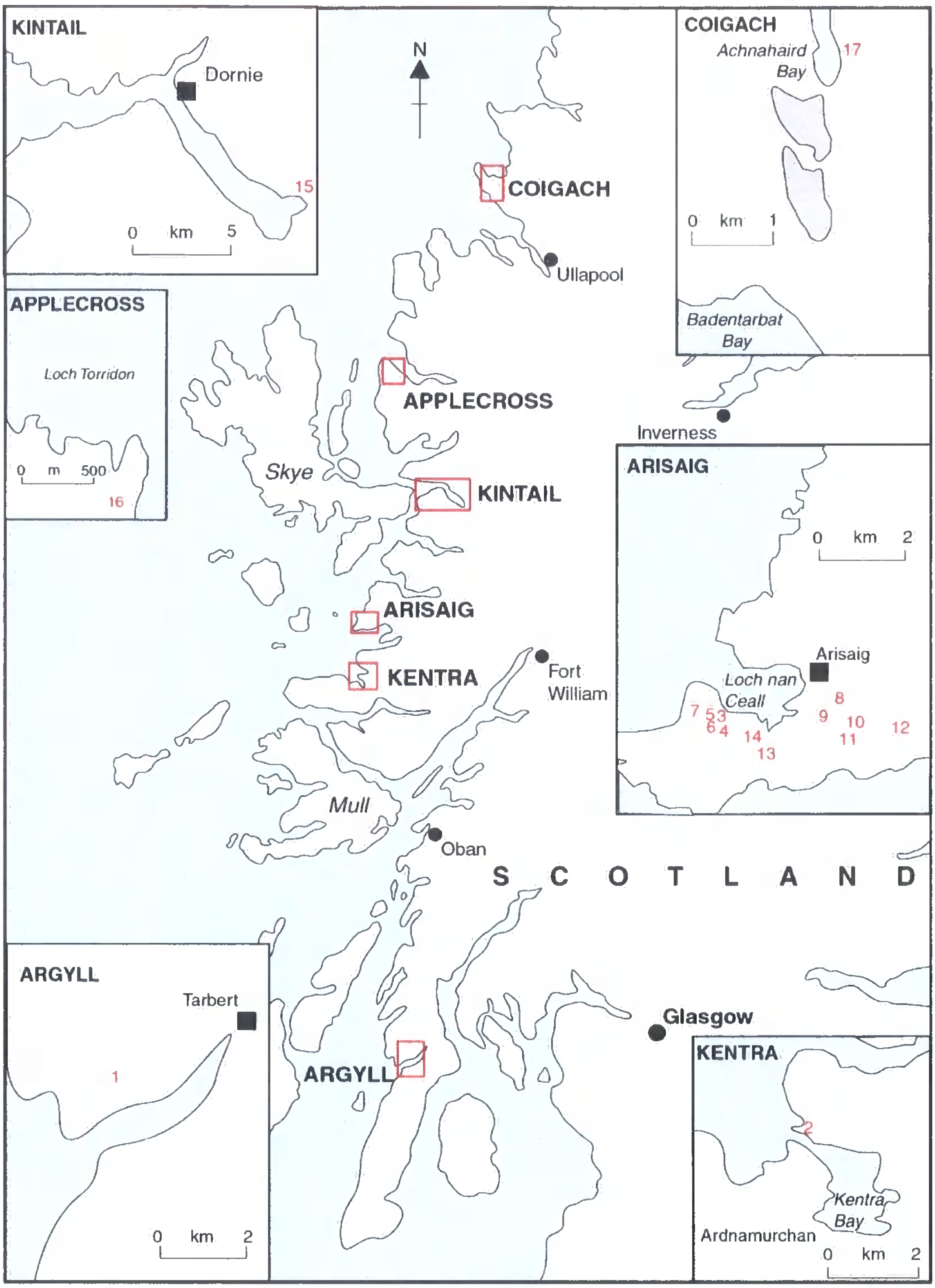


Figure 8.1: The location of the fossil isolation basins investigated in western Scotland (after Shennan *et al.*, 2000a). The red-coloured numbers correspond to those sites listed in Table 8.1.

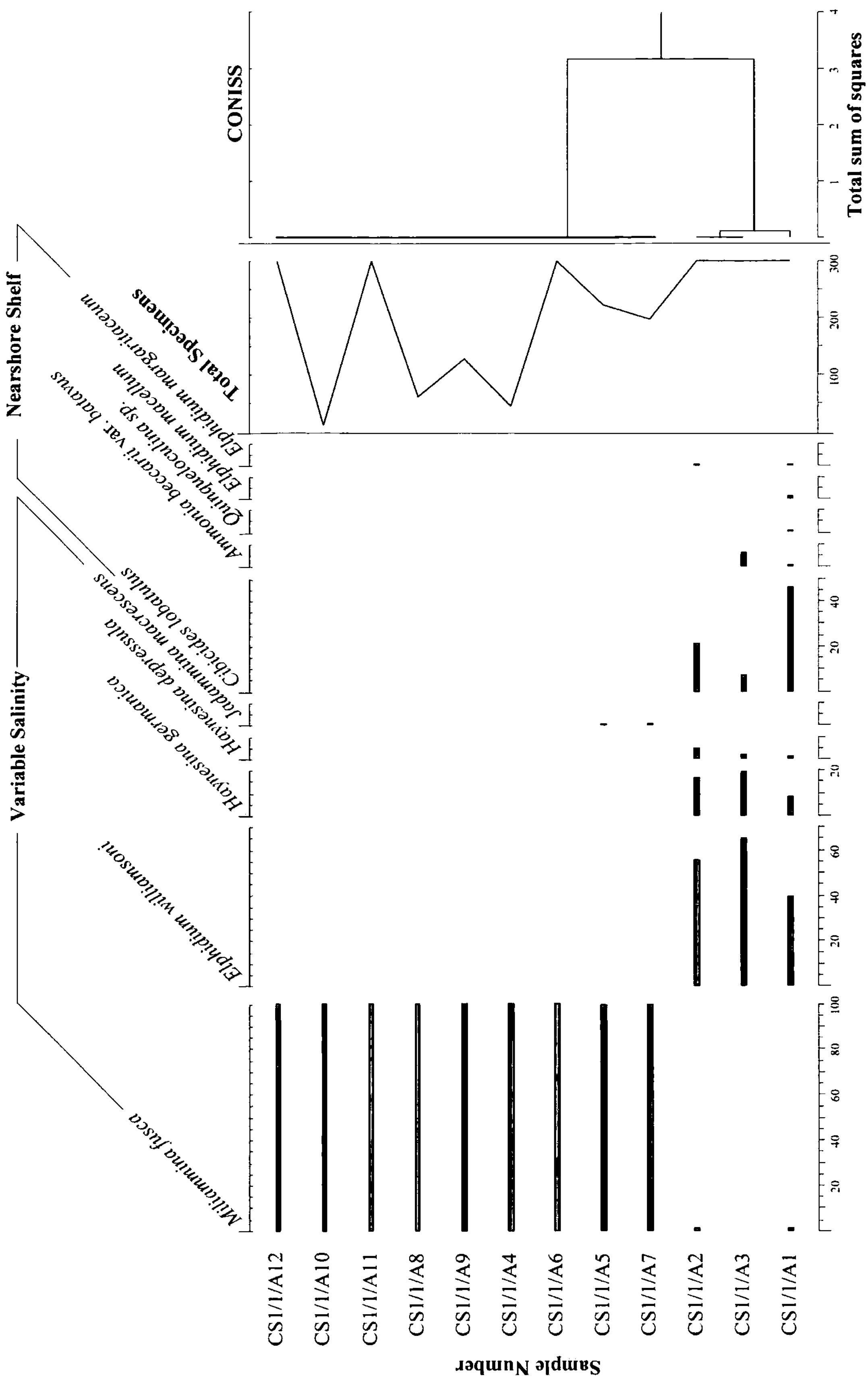


Figure A3.1.1: Foraminiferal assemblages collected from Oban Trumisgarry, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

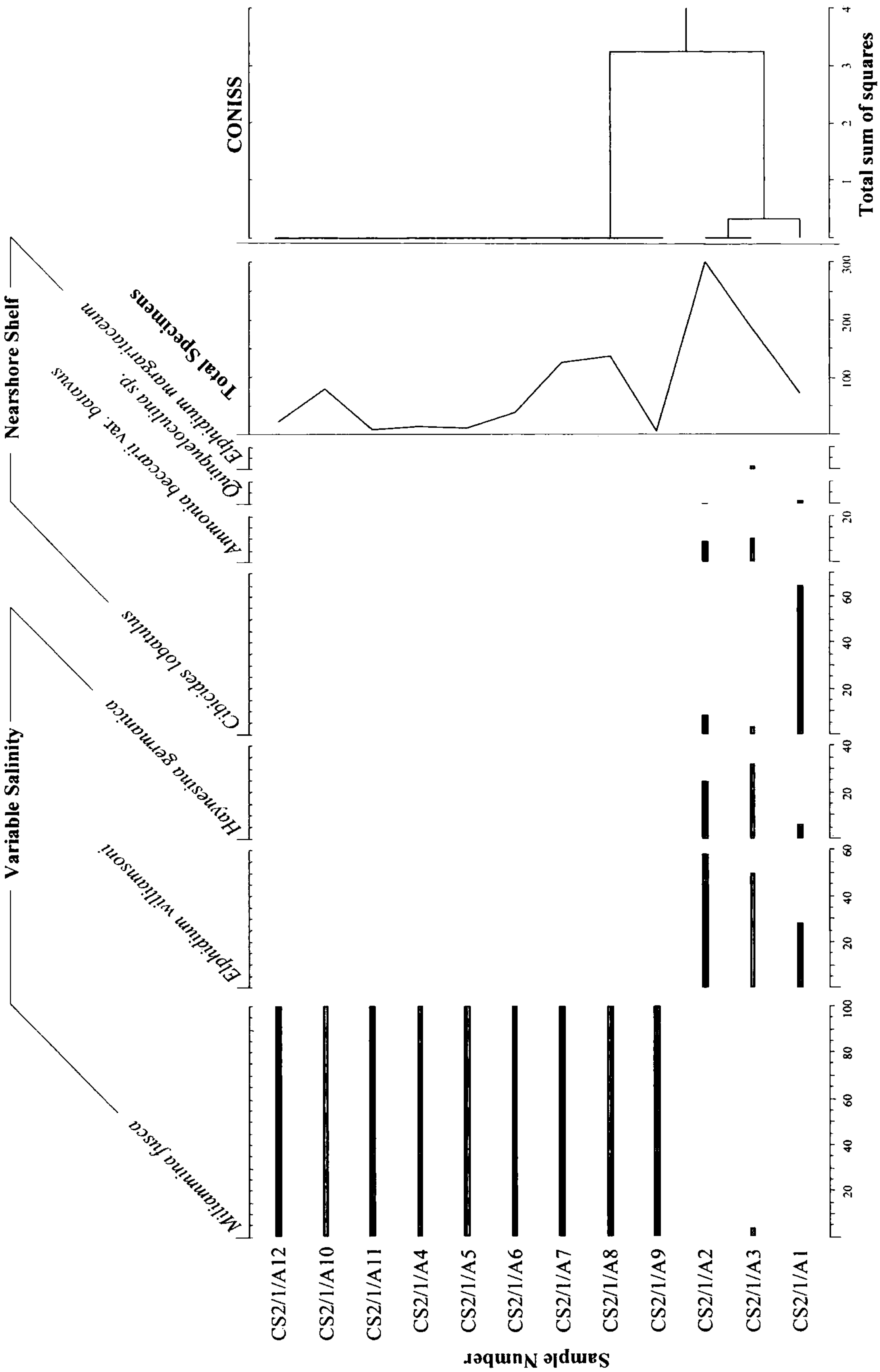


Figure A3.1.2: Foraminiferal assemblages collected from Oban Trumisgarry, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

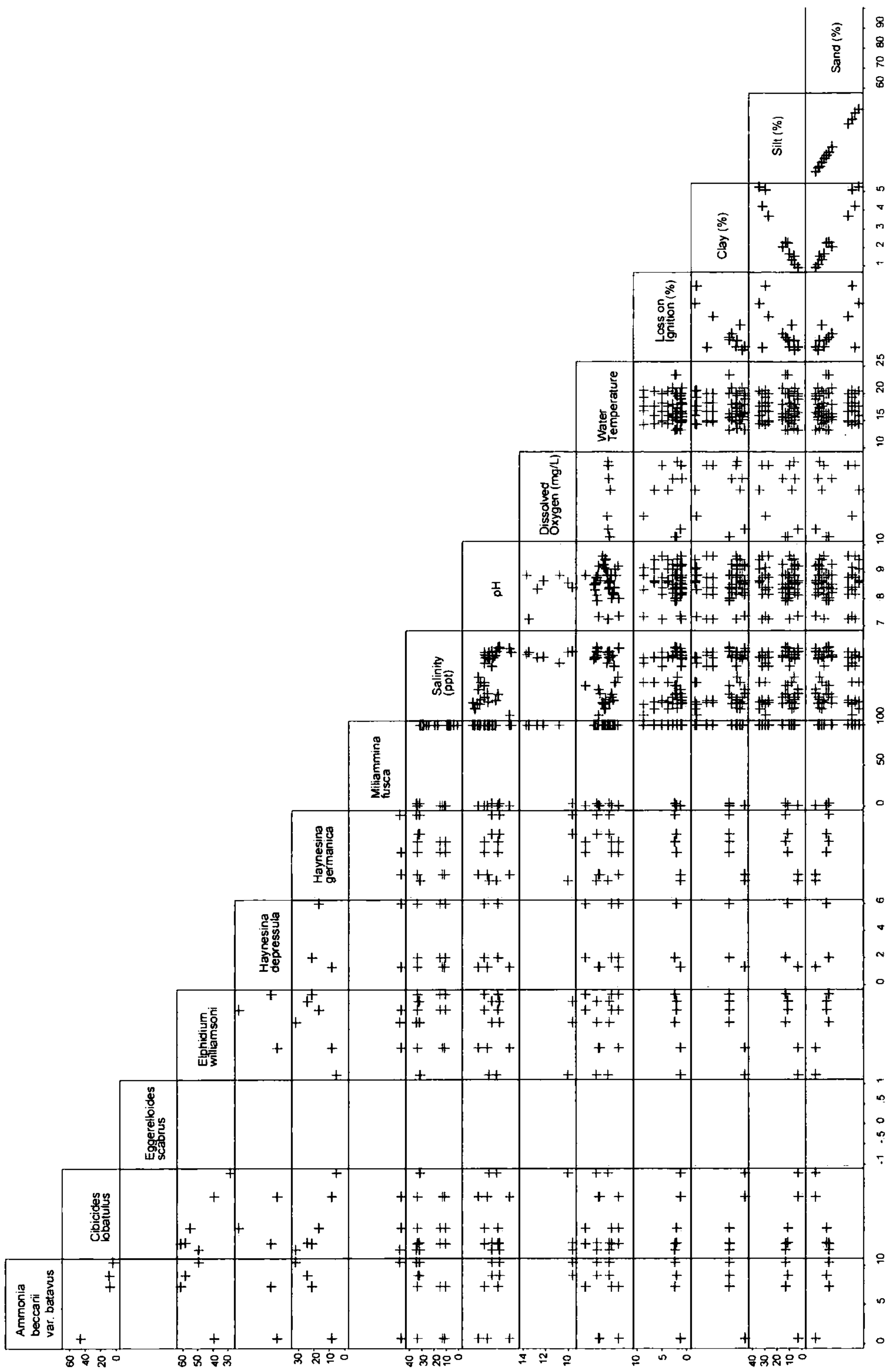


Figure A3.1.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Oban Trumisgarry, Isle of North Uist

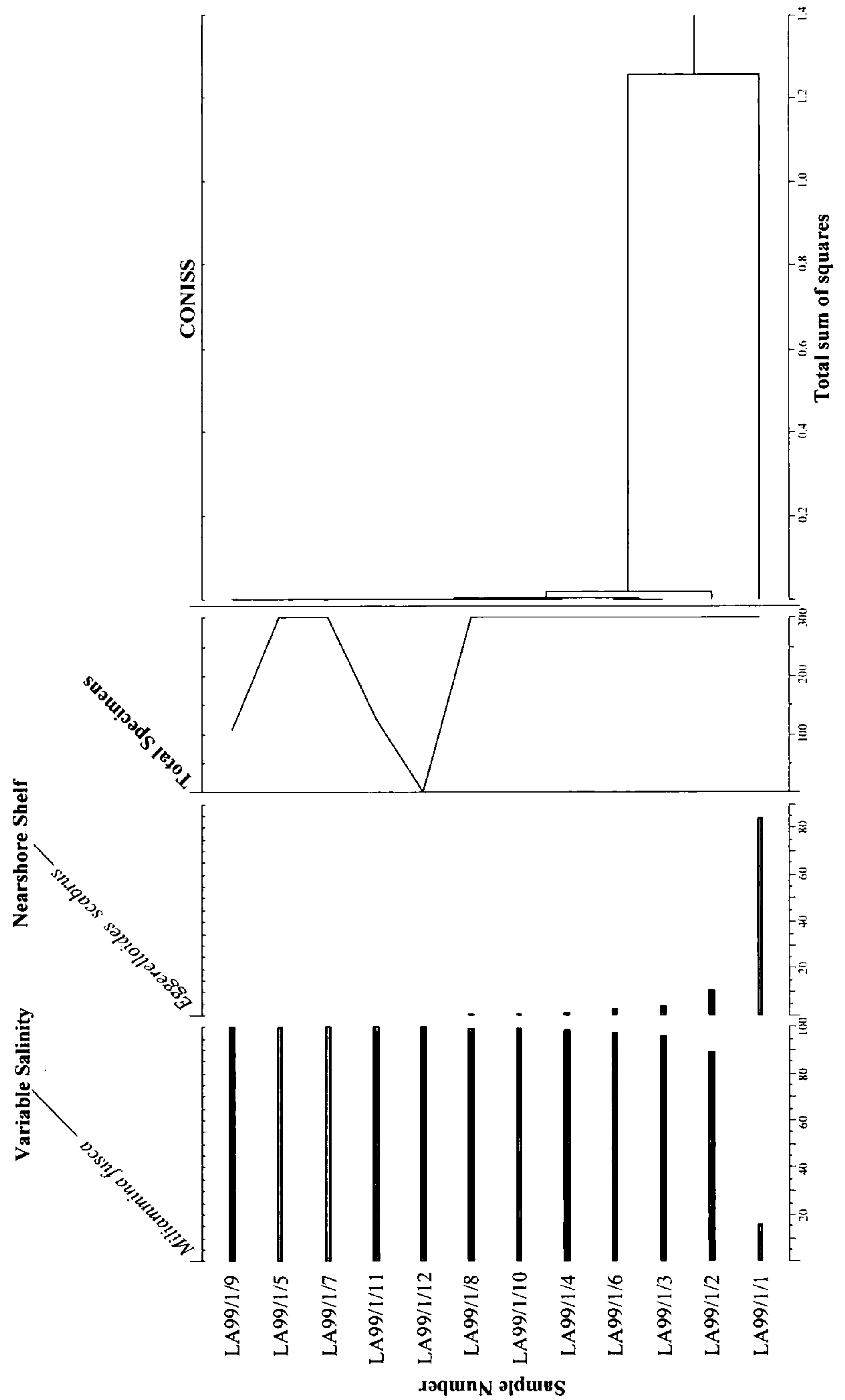


Figure A3.2.1: Foraminiferal assemblages collected from Alioter Lagoon, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

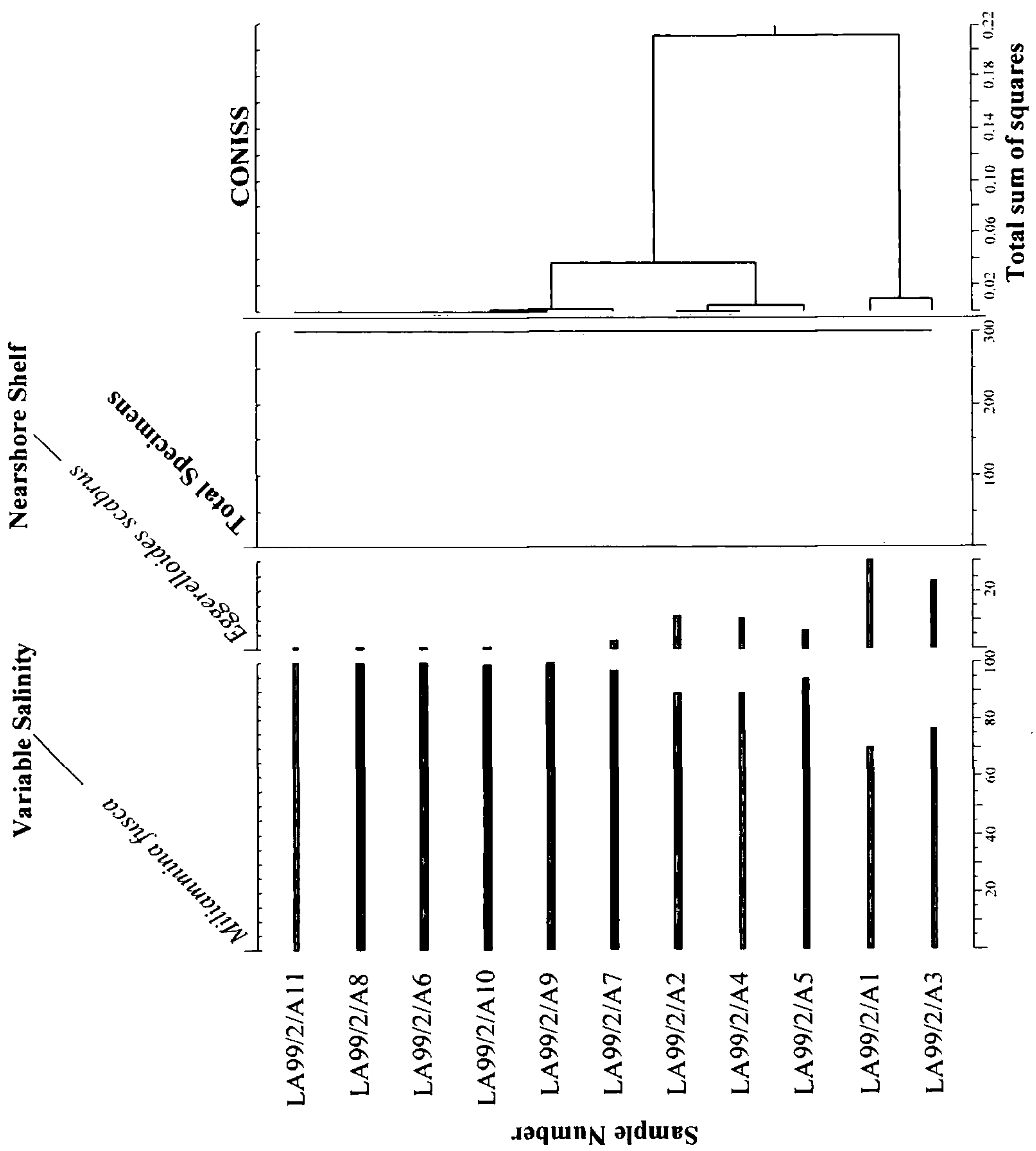


Figure A3.2.2: Foraminiferal assemblages collected from Alioter Lagoon, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

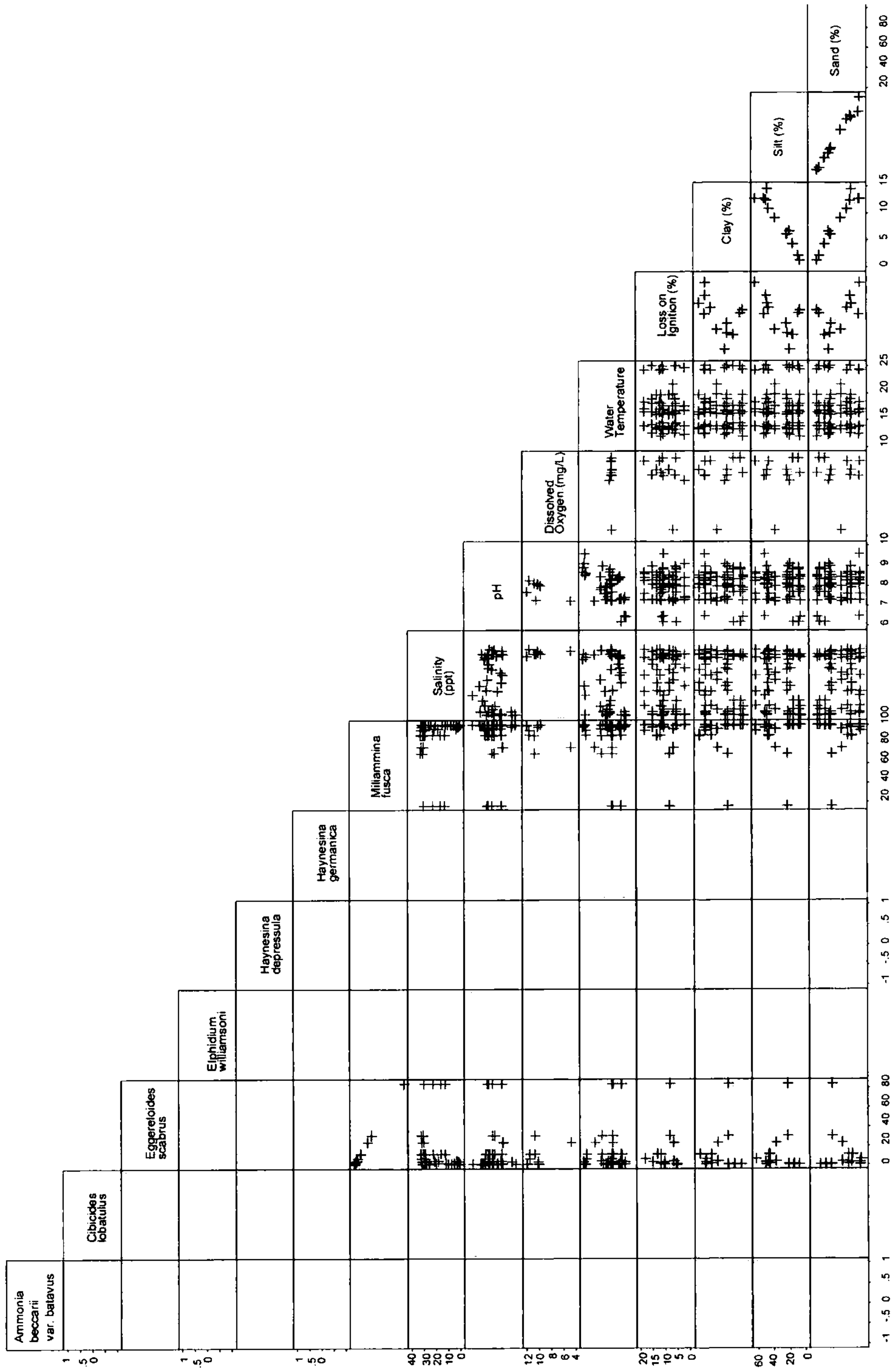


Figure A3.2.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Alioter Lagoon, Isle of North Uist.

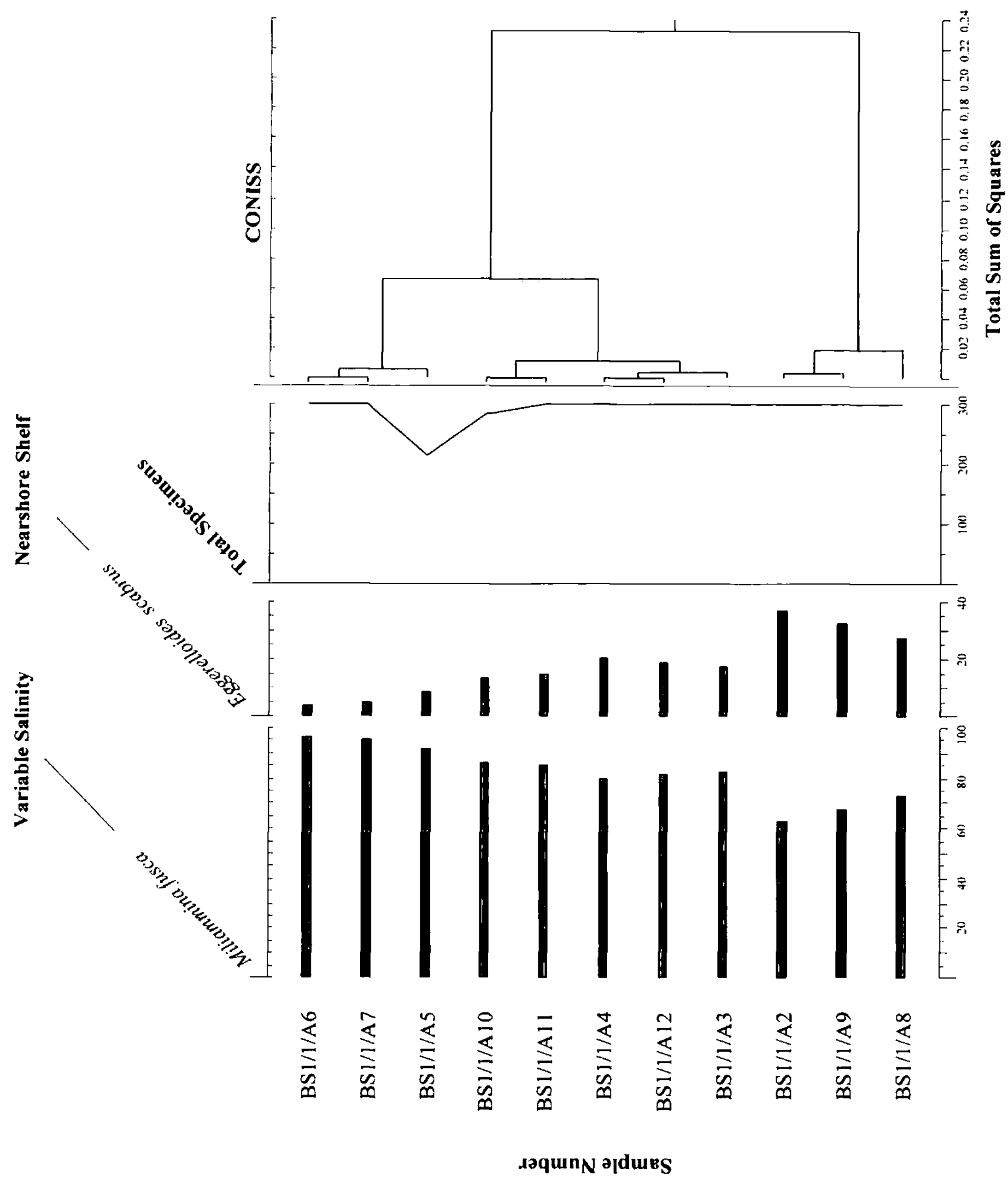


Figure A3.3.1: Foraminiferal assemblages collected from Bac-a-Stoc Lagoon, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

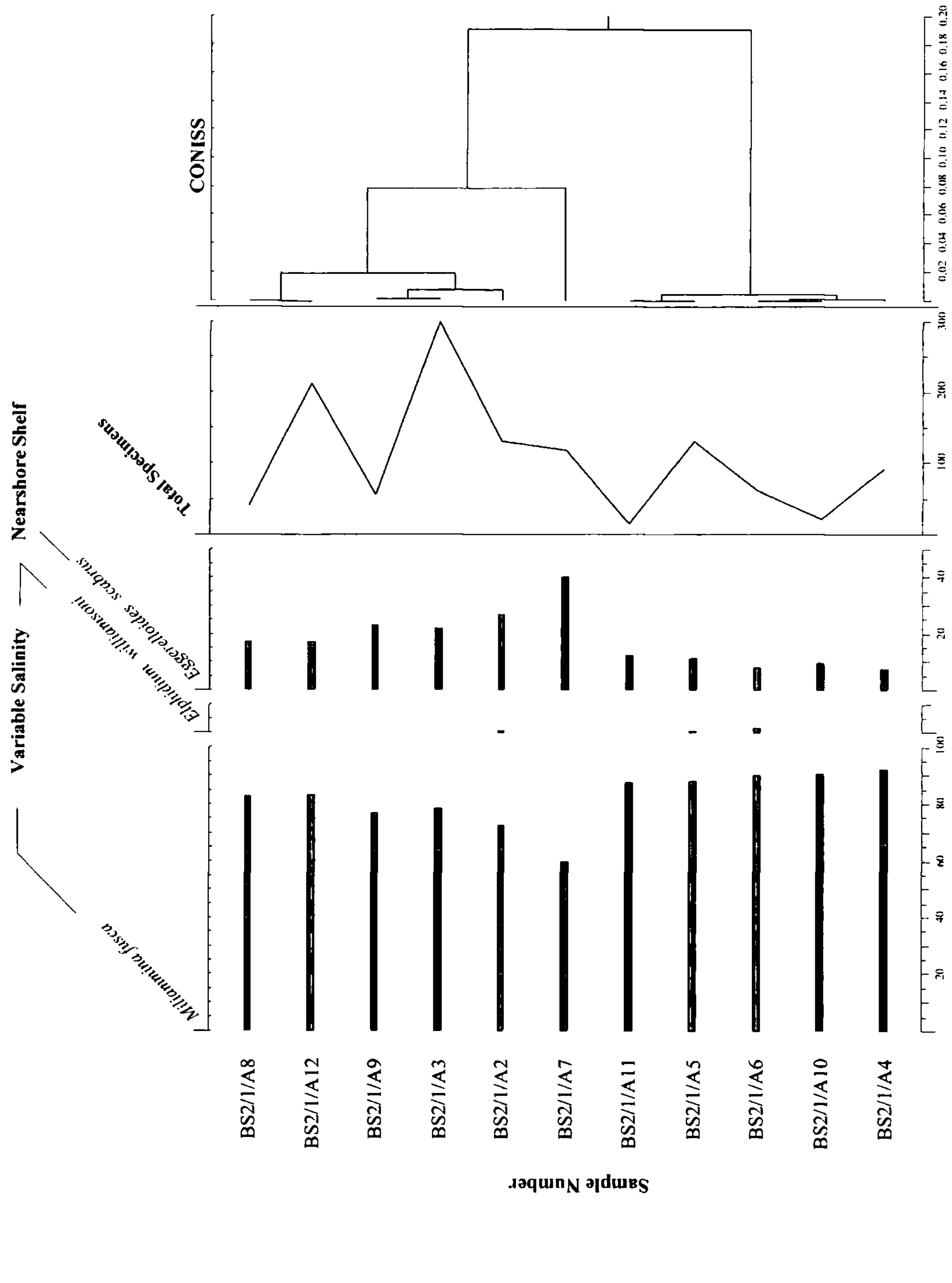


Figure A3.3.2: Foraminiferal assemblages collected from Bac-a-Stoc Lagoon, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

Figure A3.3.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Bac-a-Stoc Lagoon, Isle of North Uist.

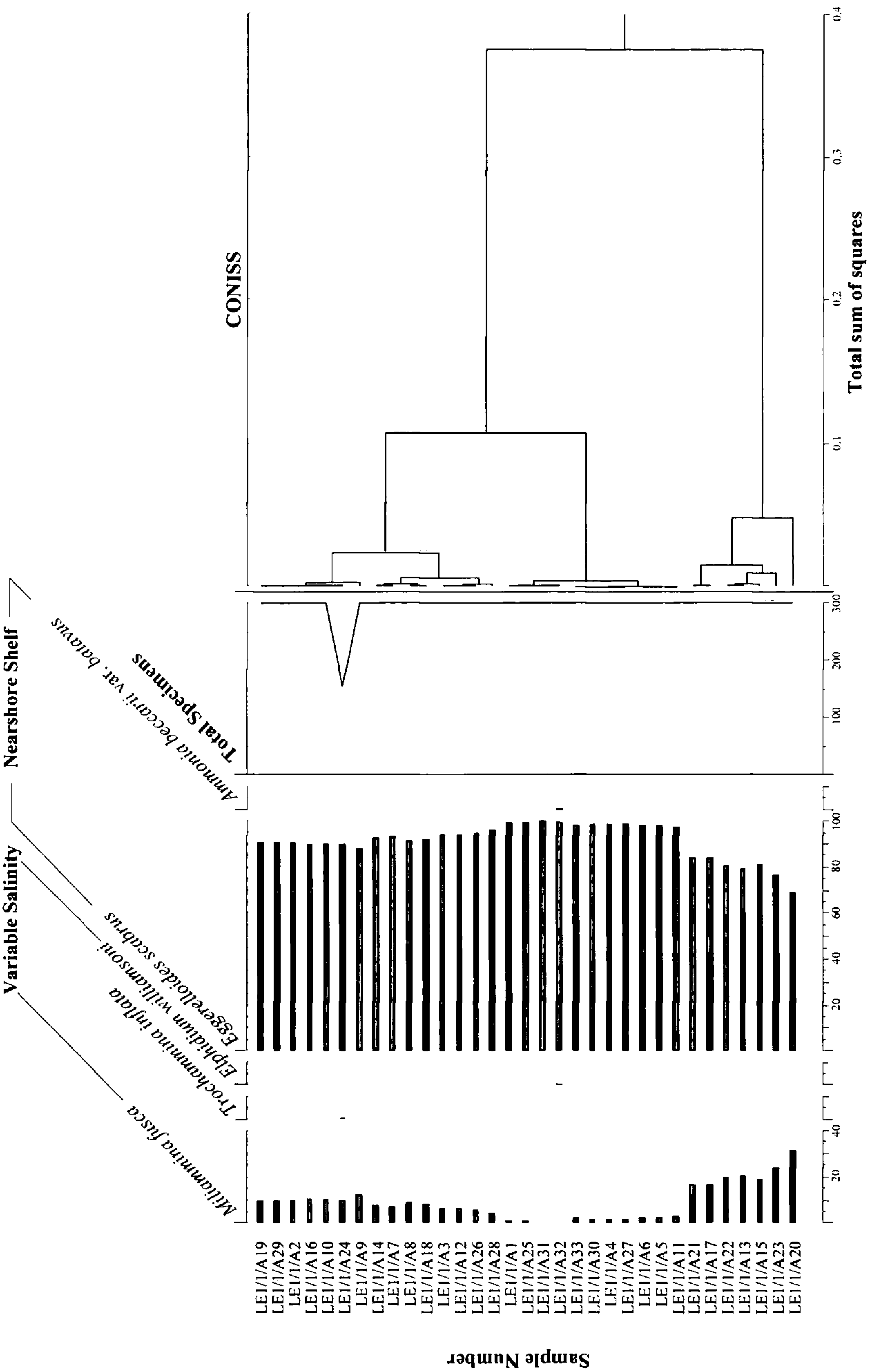


Figure A3.4.1: Foraminiferal assemblages collected from Locheport 1, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

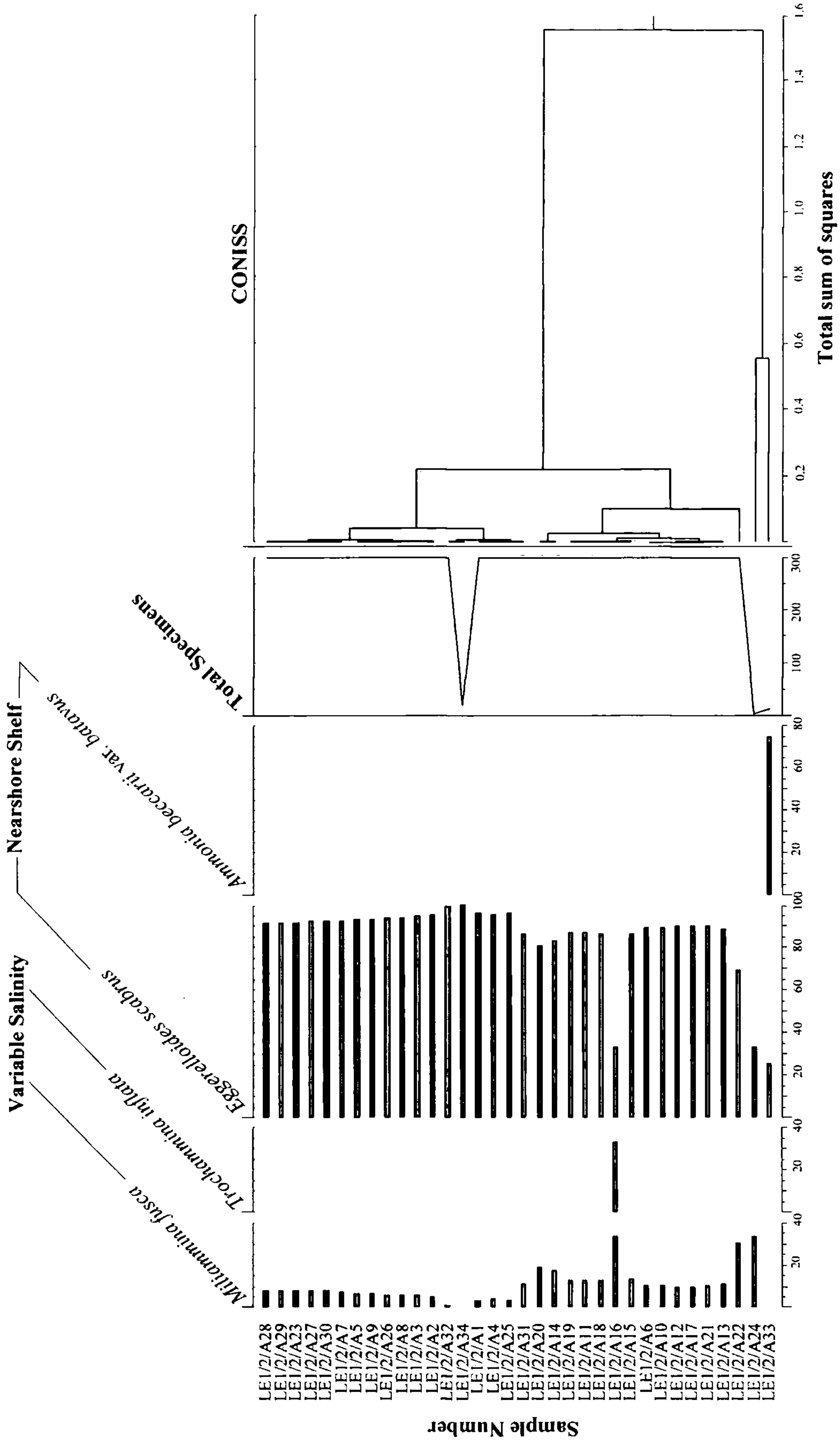


Figure A3.4.2: Foraminiferal assemblages collected from Locheport 1, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

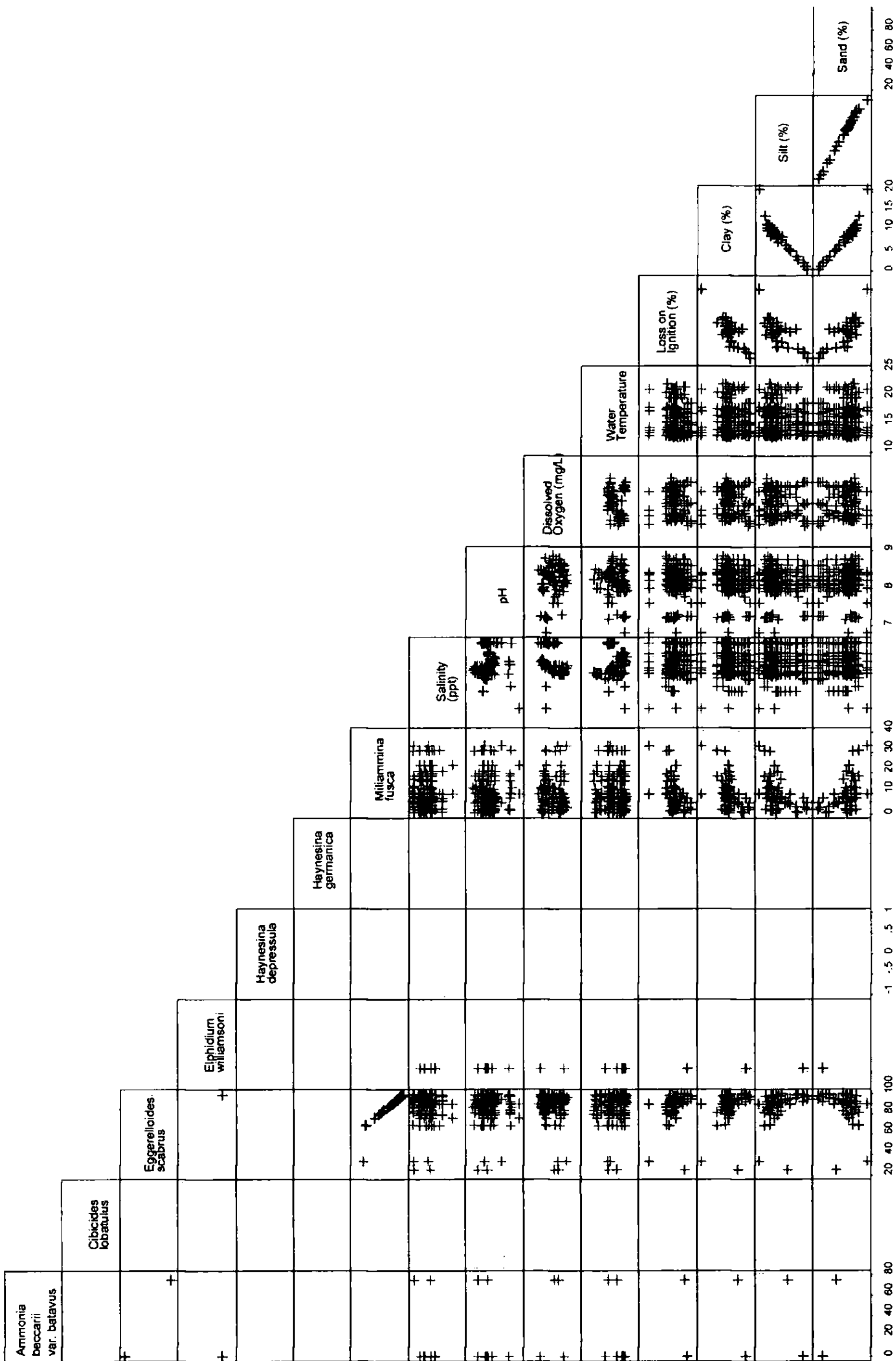


Figure A3.4.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Locheport 1, Isle of North Uist.

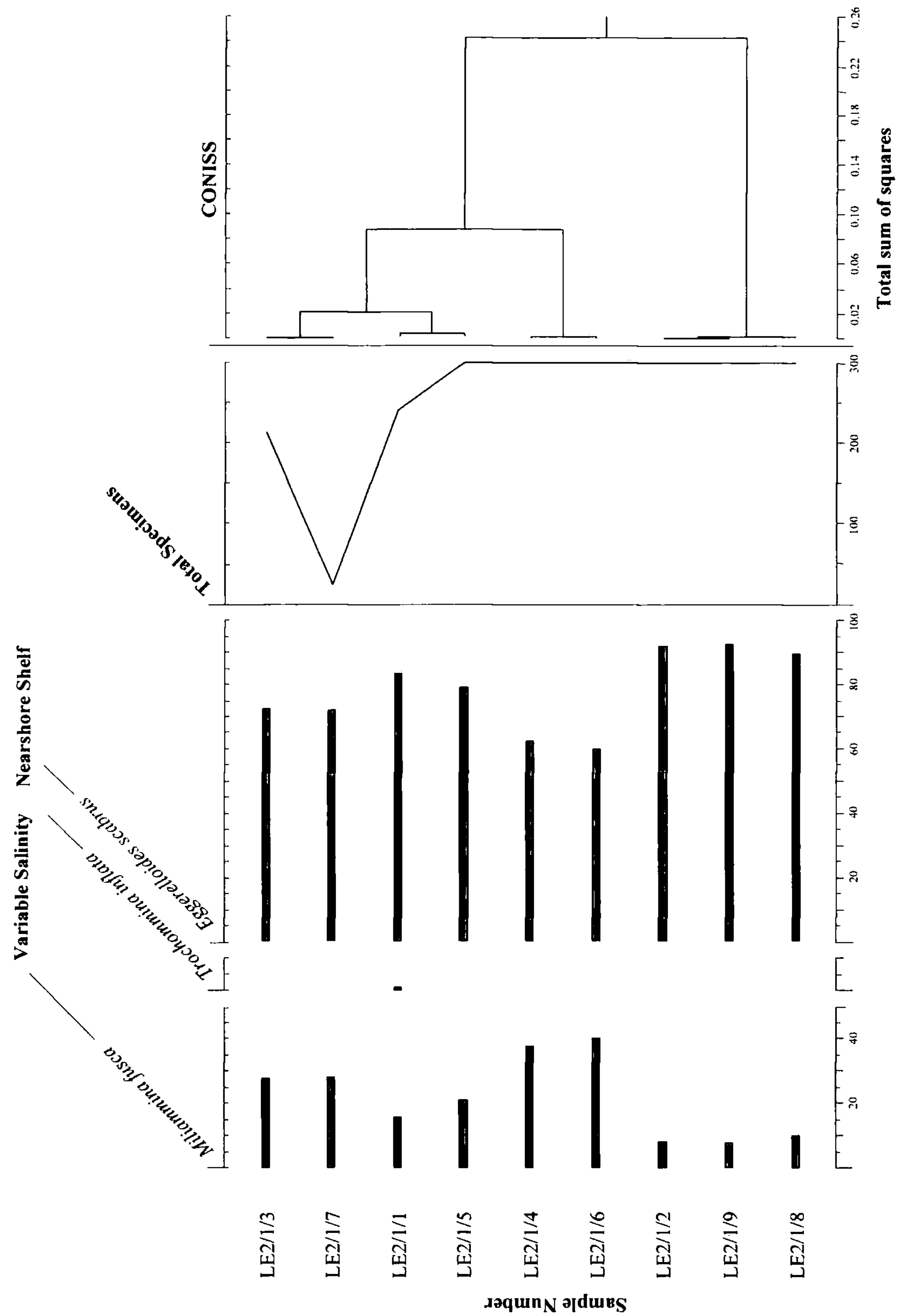


Figure A3.5.1: Foraminiferal assemblages collected from Locheport 2, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

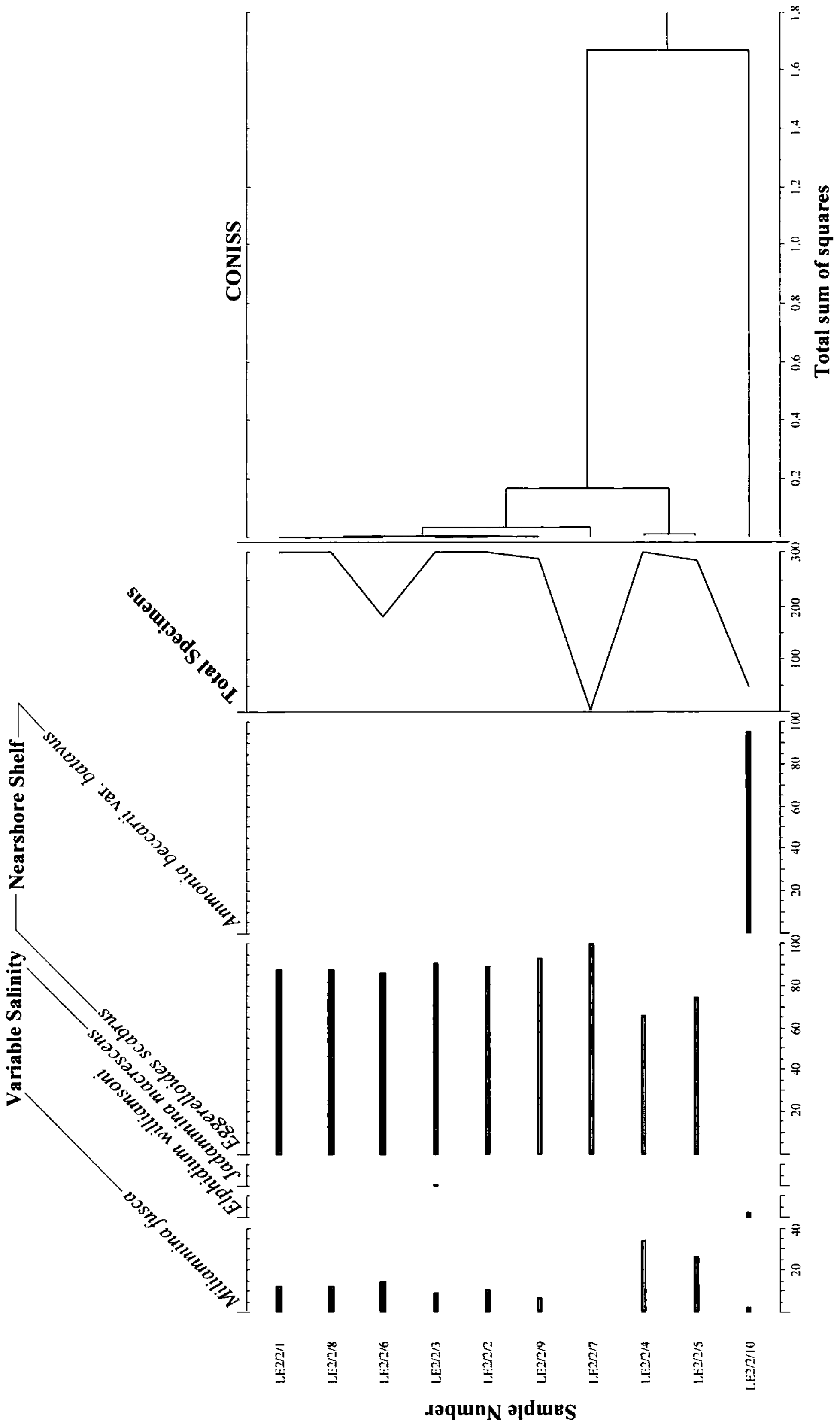


Figure A3.5.2: Foraminiferal assemblages collected from Locheport 2, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

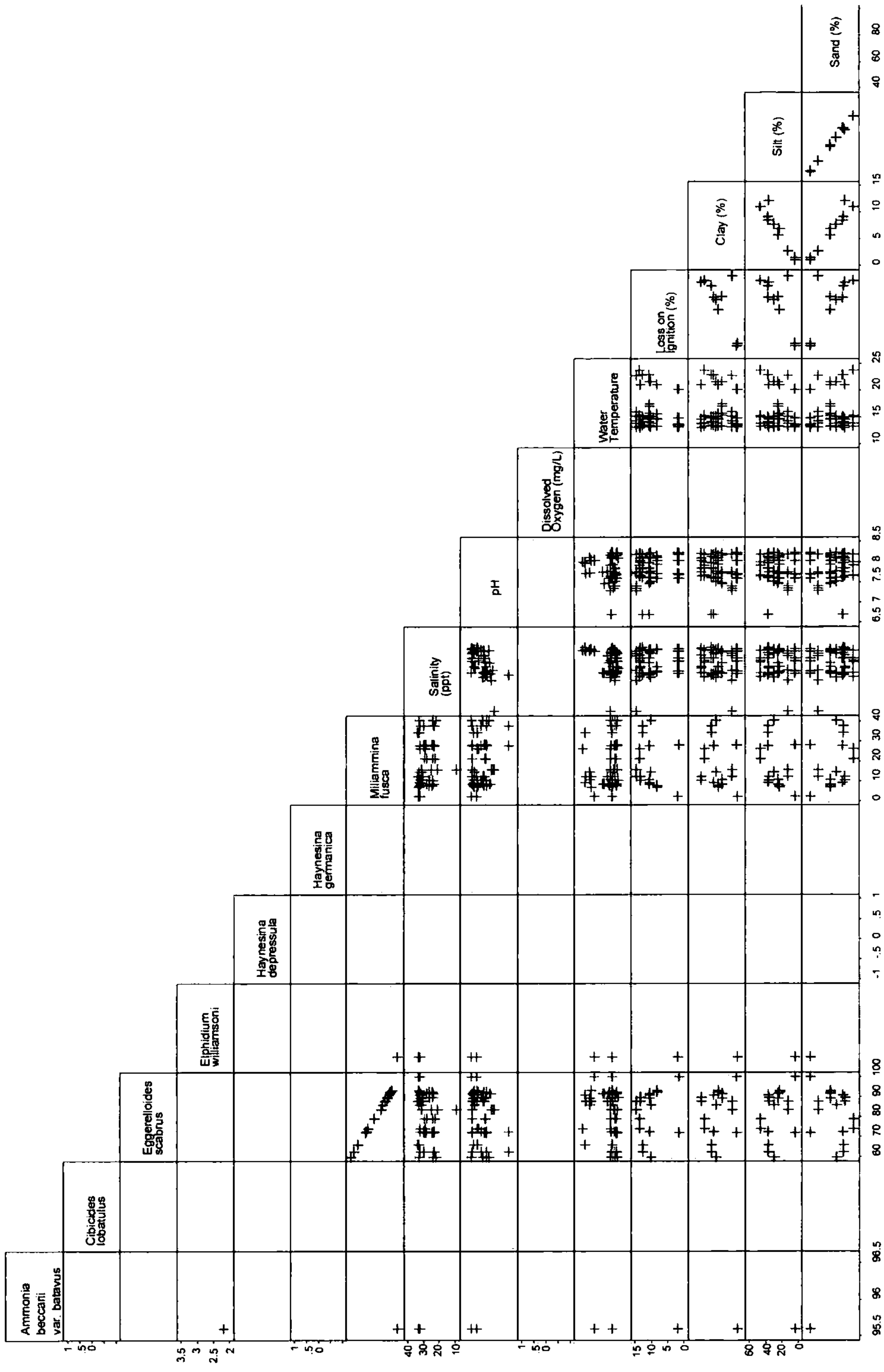


Figure A3.5.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Locheport 2, Isle of North Uist.

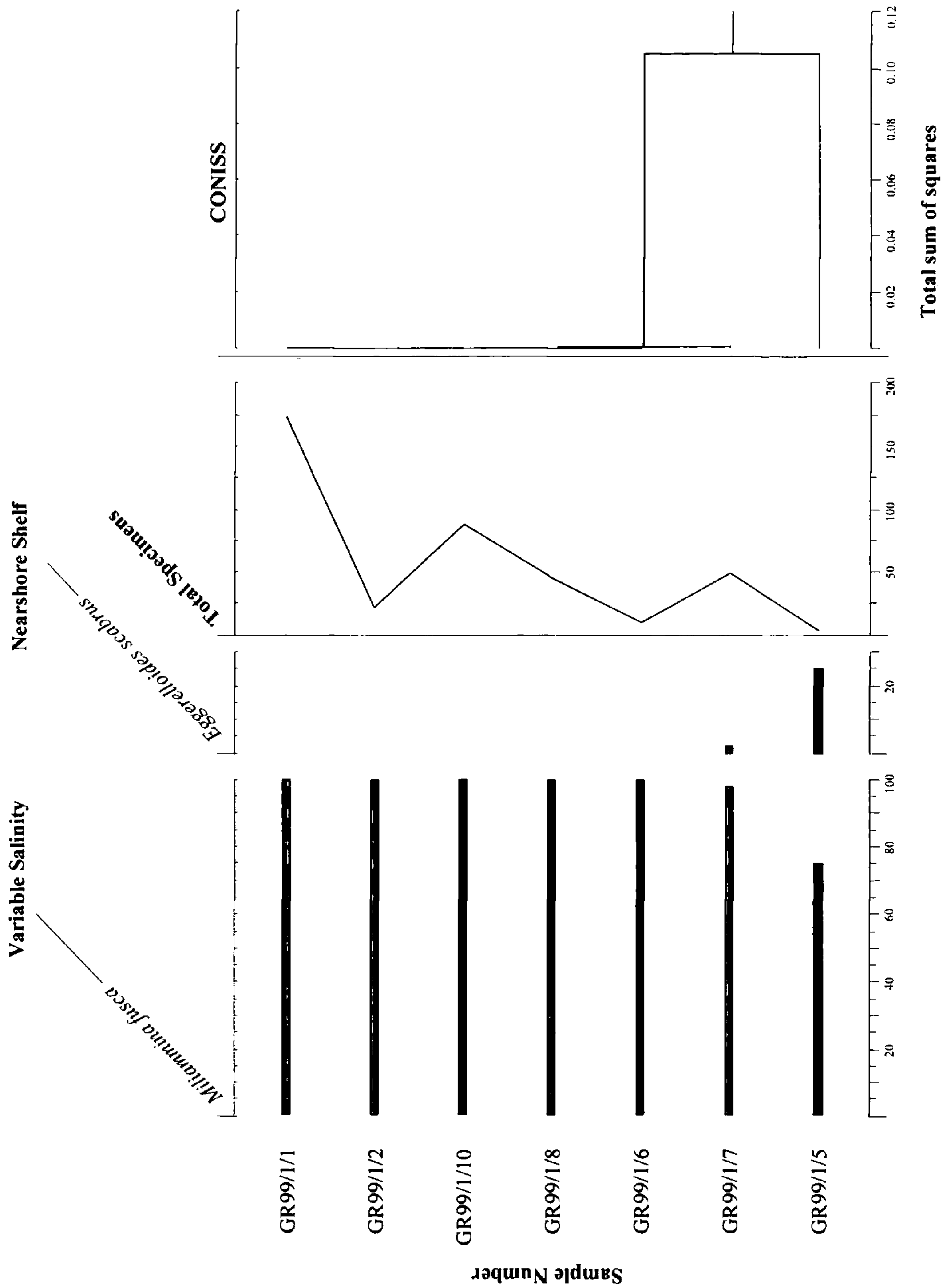


Figure A3.6.1: Foraminiferal assemblages collected from Grimsay, Isle of North Uist, during May 1999. The CONISS cluster analysis was carried out with no data transformation.

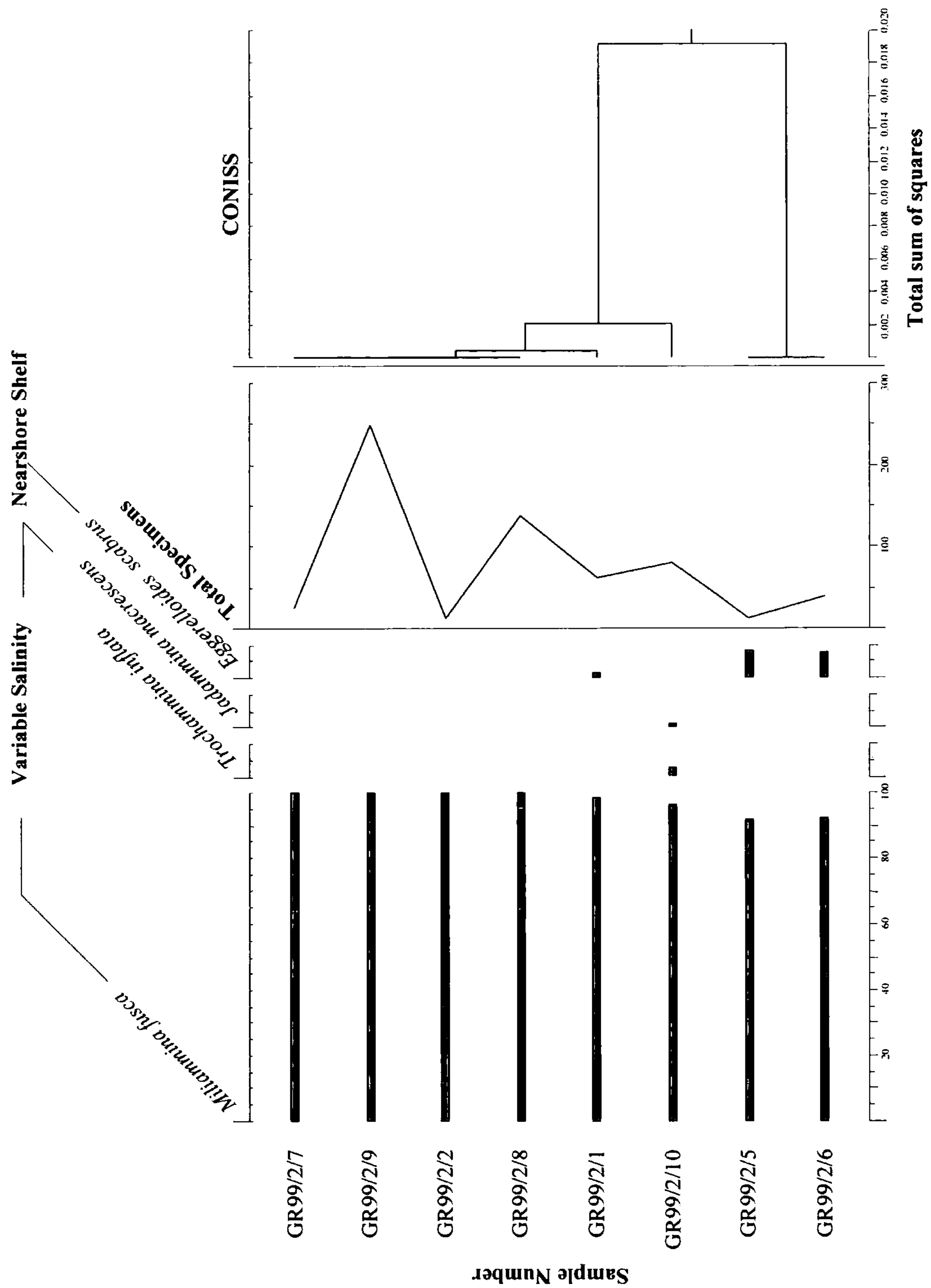


Figure A3.6.2: Foraminiferal assemblages collected from Grimsay, Isle of North Uist, during September 1999. The CONISS cluster analysis was carried out with no data transformation.

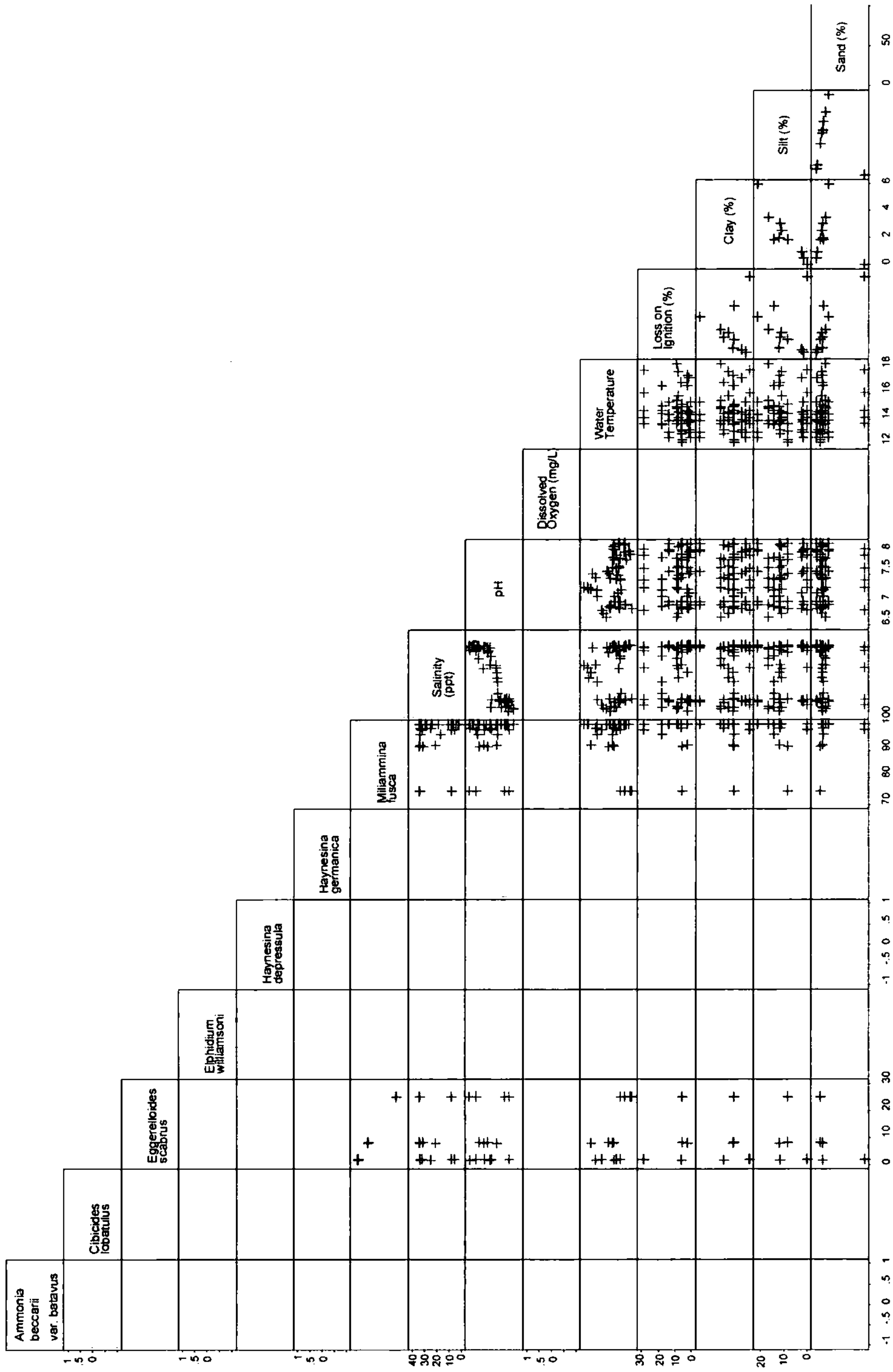


Figure A3.6.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Grimsay, Isle of North Uist.

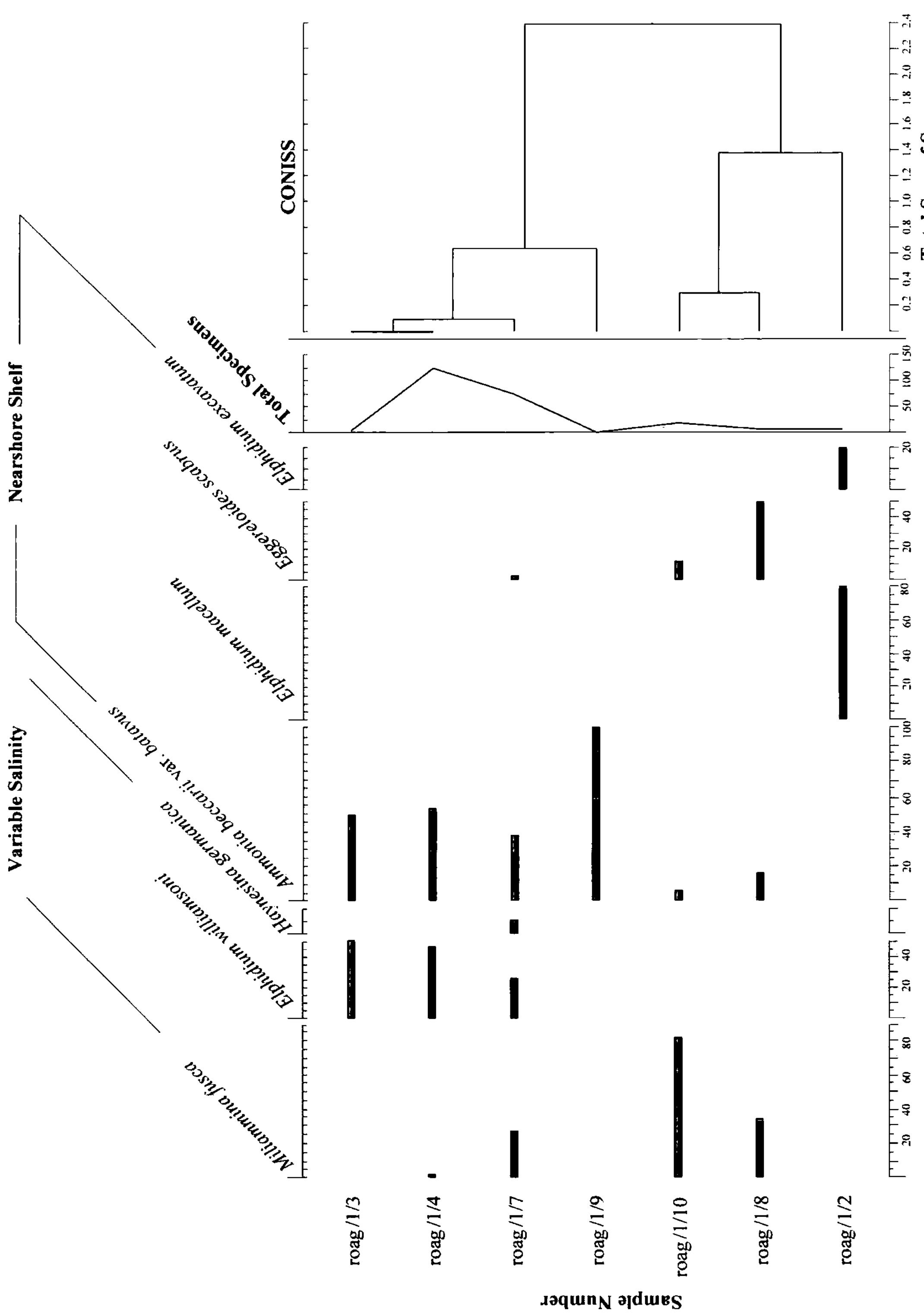


Figure A3.7.1: Foraminiferal assemblages collected from Pool Roag, Isle of Skye, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

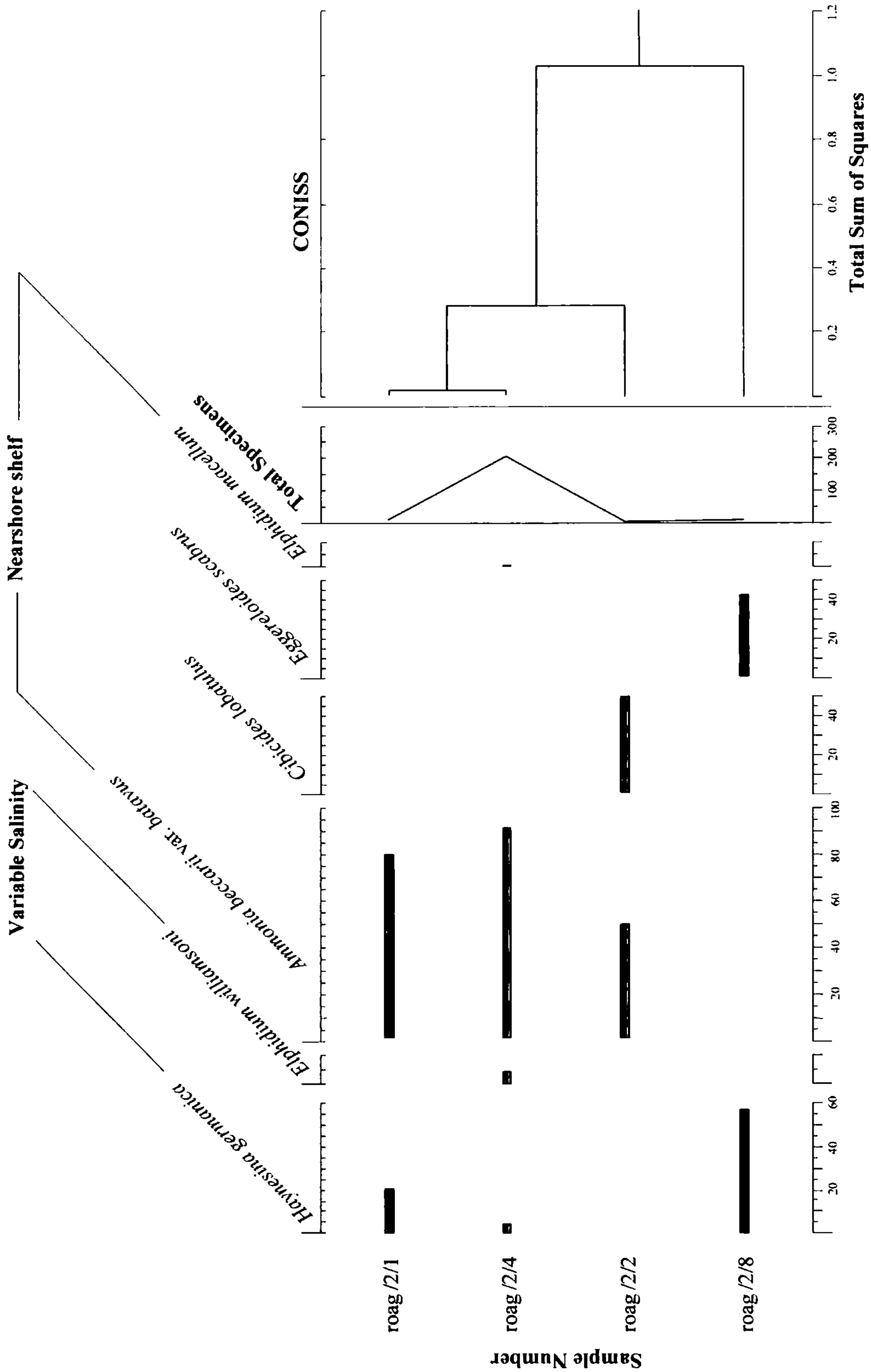


Figure A3.7.2: Foraminiferal assemblages collected from Pool Roag, Isle of Skye, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

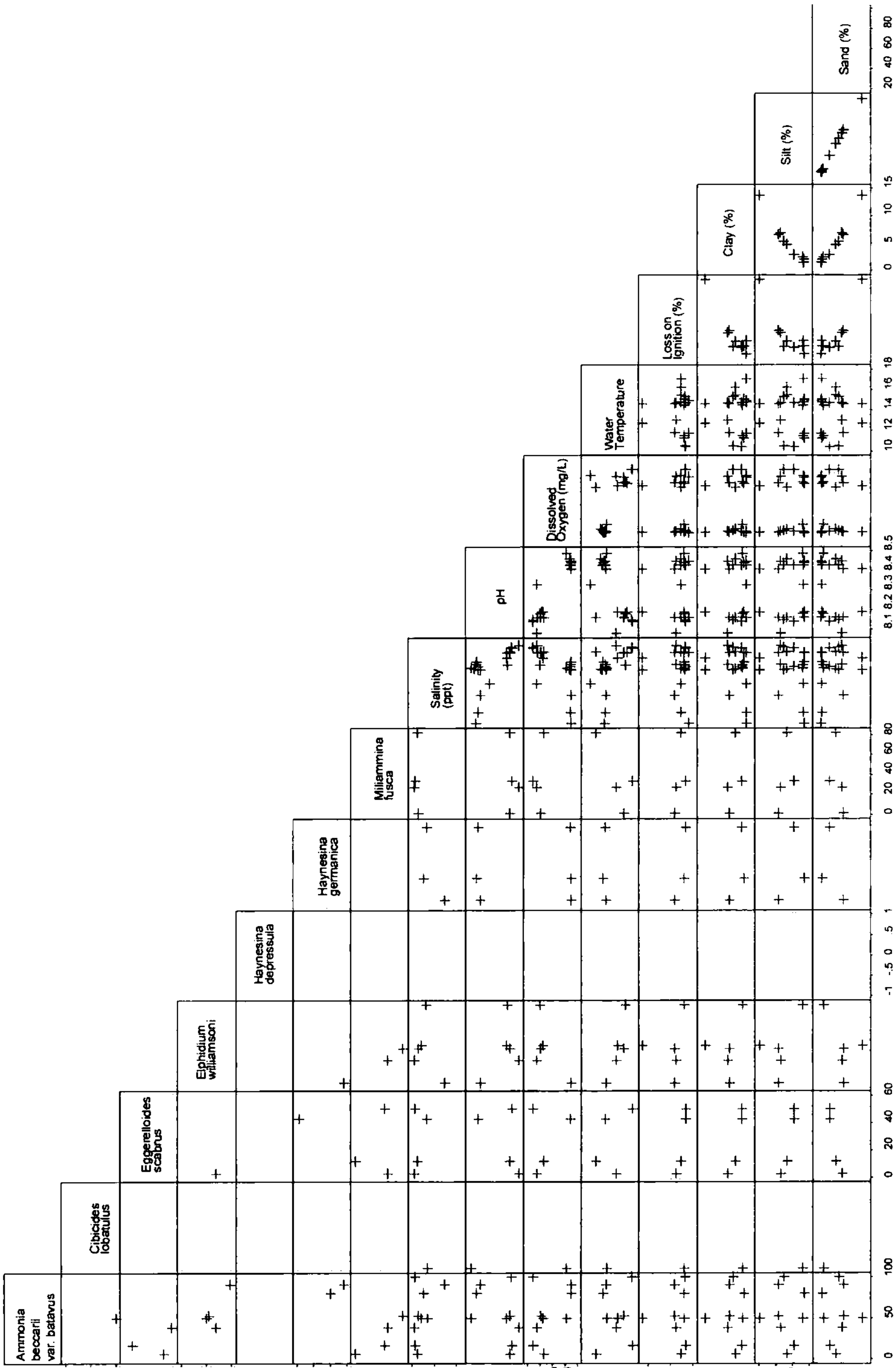


Figure A3.7.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Pool Roag, Isle of Skye.

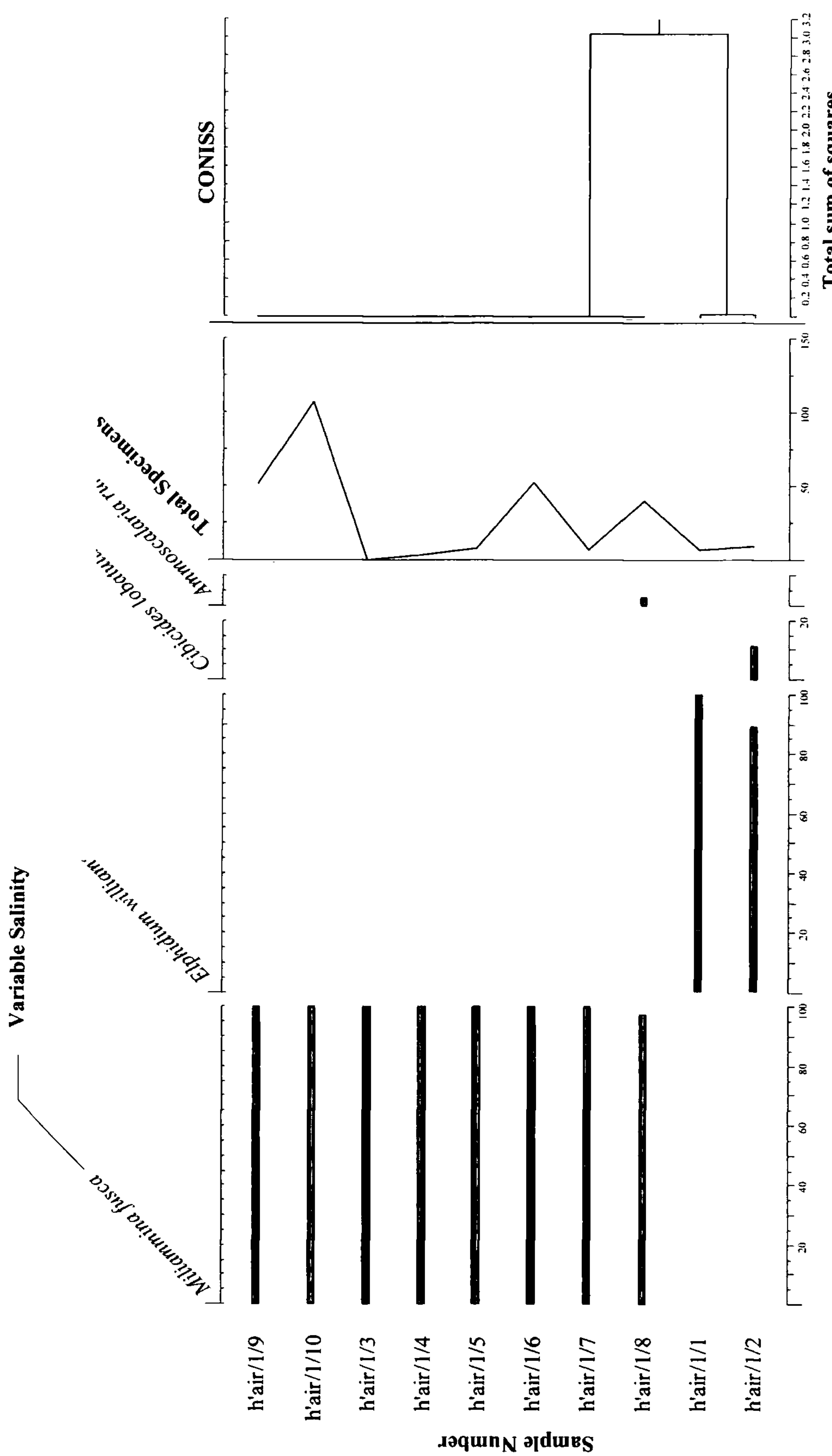


Figure A3.8.1: Foraminiferal assemblages collected from Loch na h'airde, Isle of Skye, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

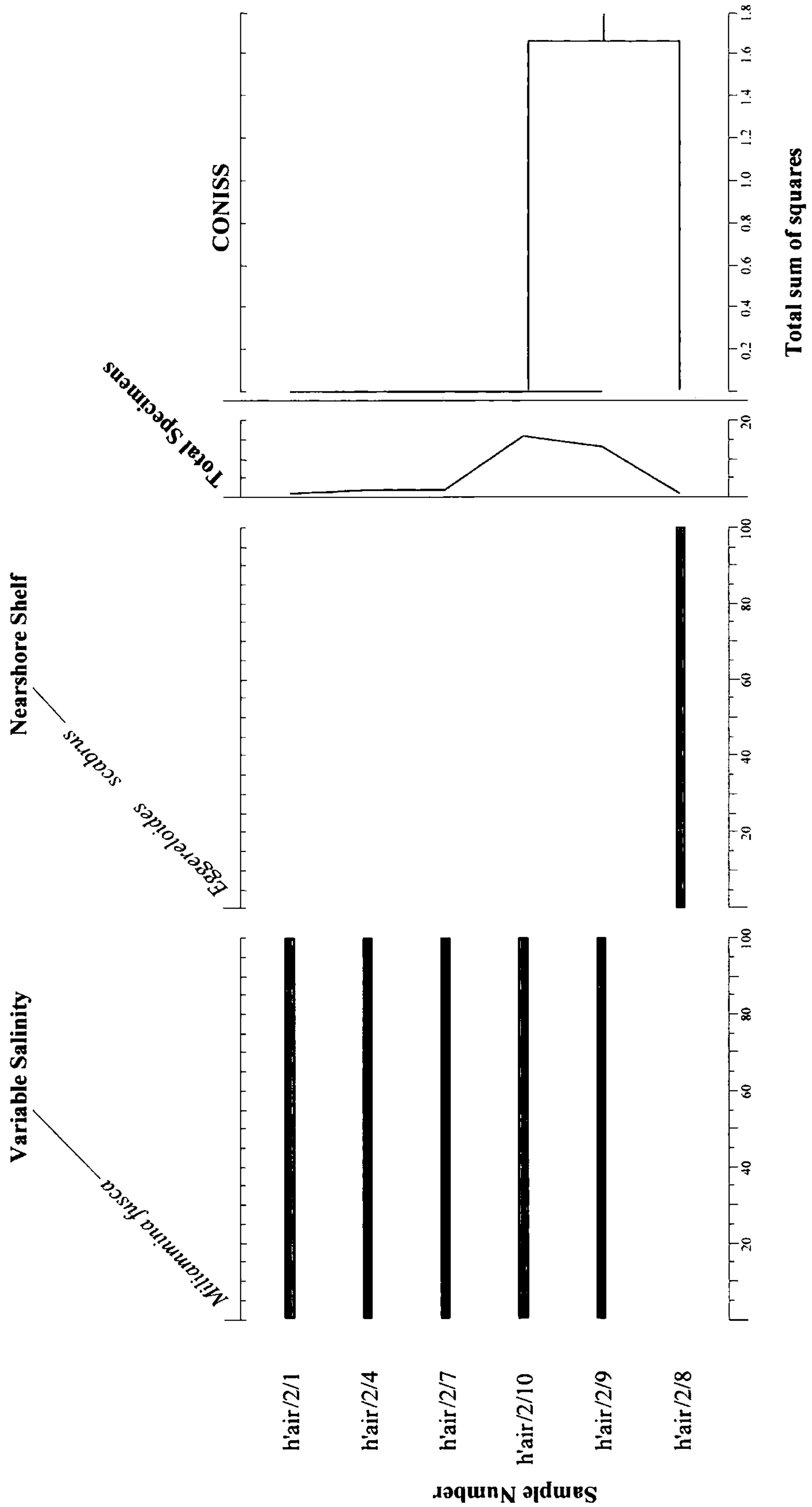


Figure A3.8.2: Foraminiferal assemblages collected from Loch na h'airde, Isle of Skye, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

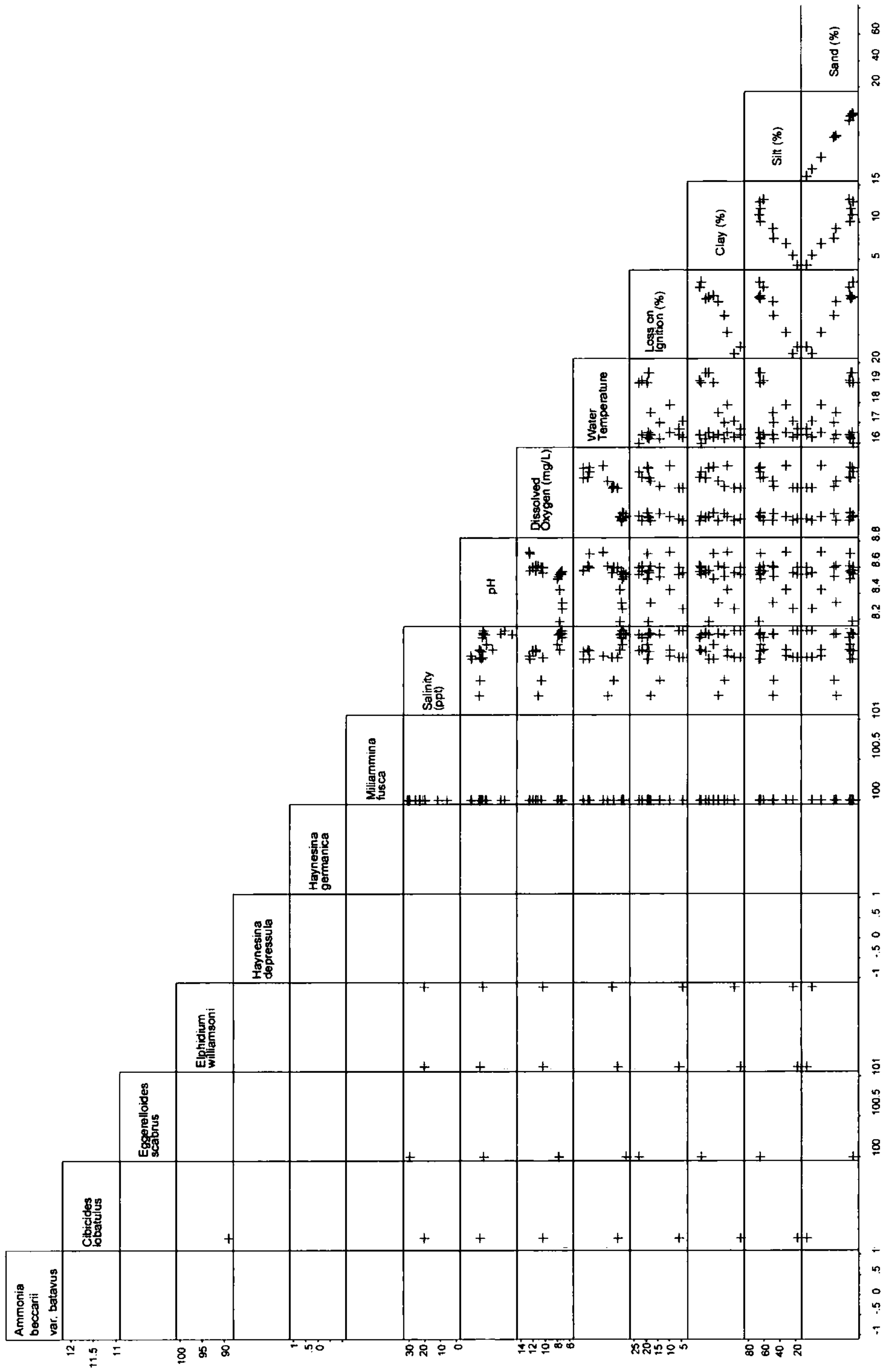


Figure A3.8.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Loch na h'airde, Isle of Skye.

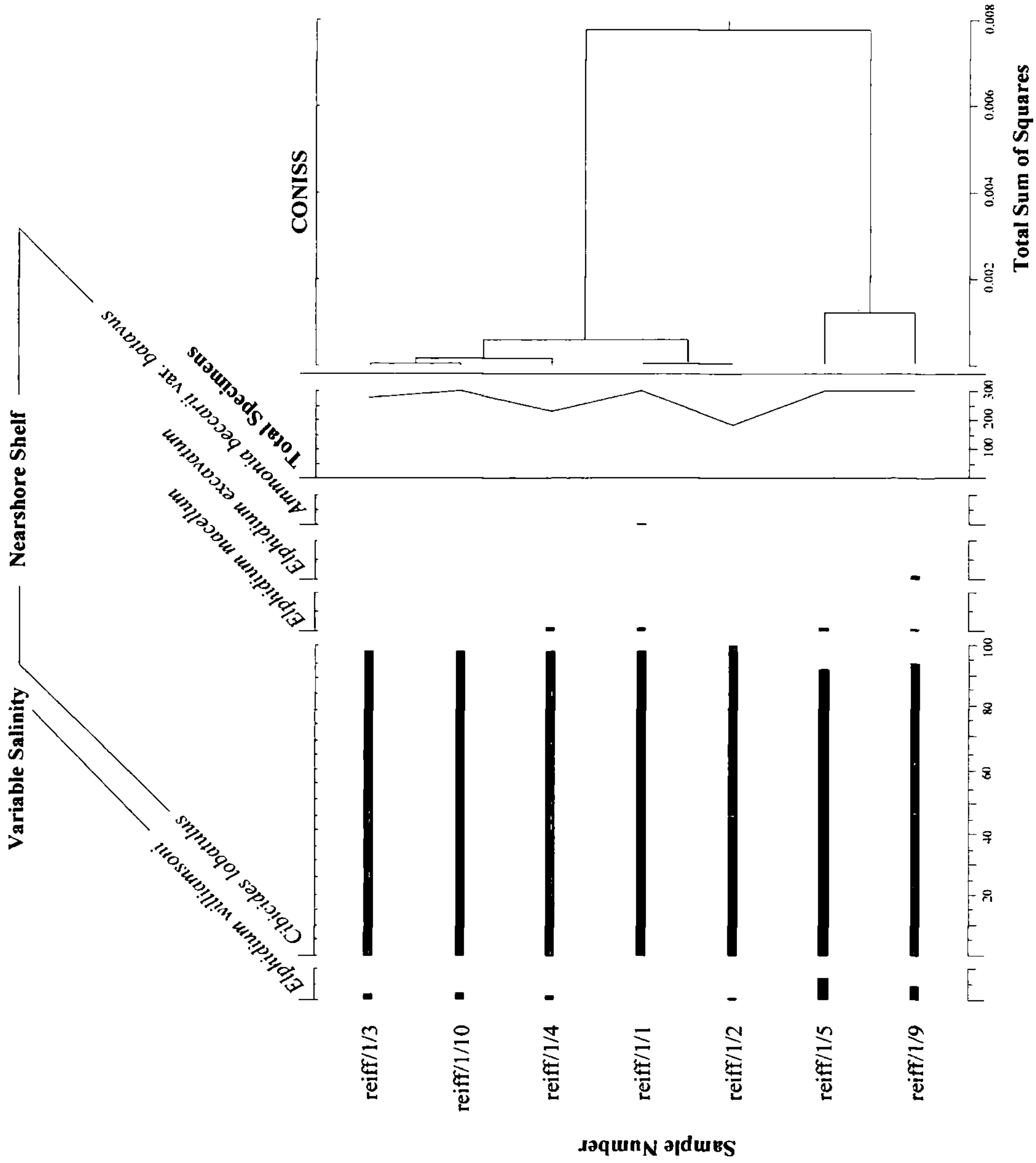


Figure A3.9.1: Foraminiferal assemblages collected from Loch of Reiff, Assynt, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

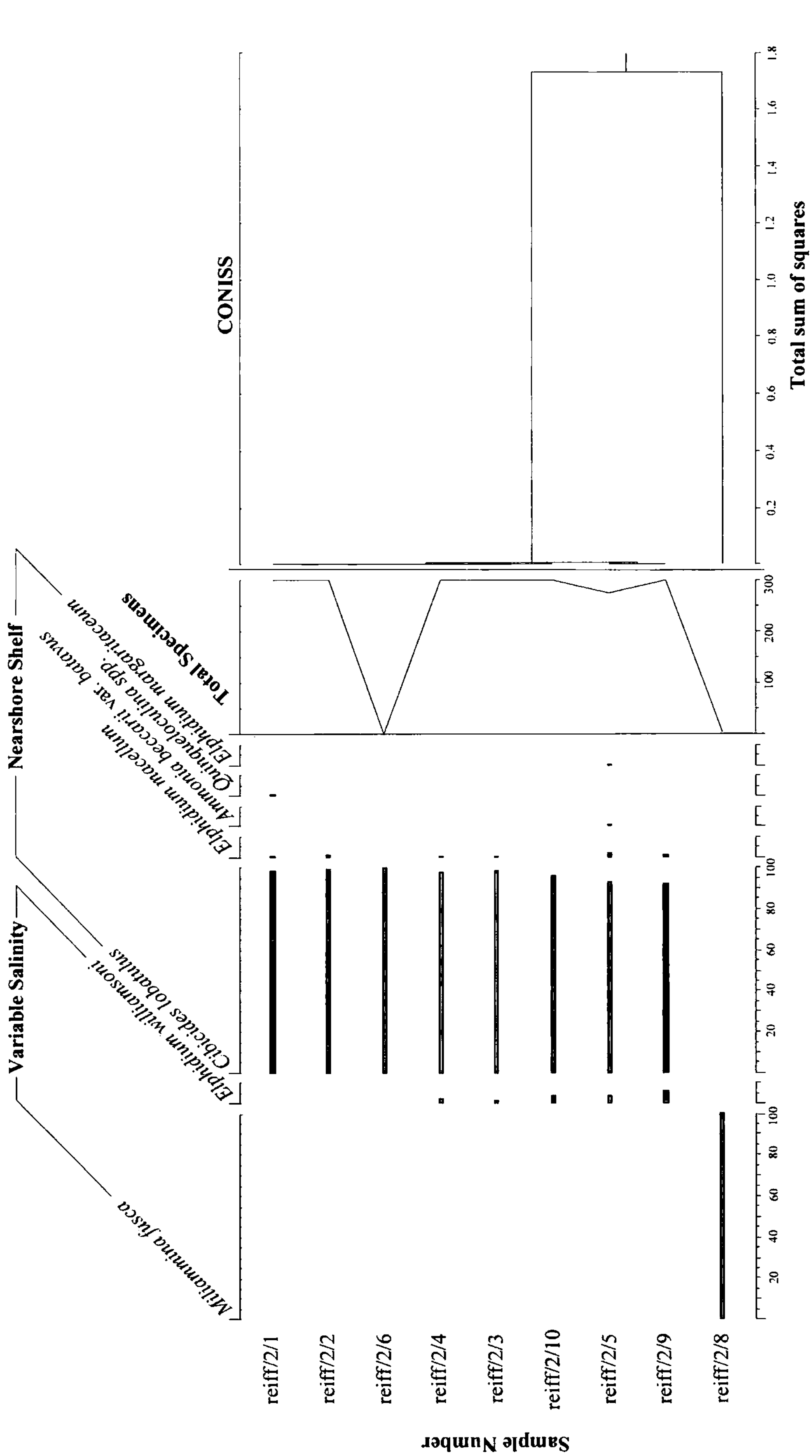


Figure A3.9.2: Foraminiferal assemblages collected from Loch of Reiff, Assynt, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

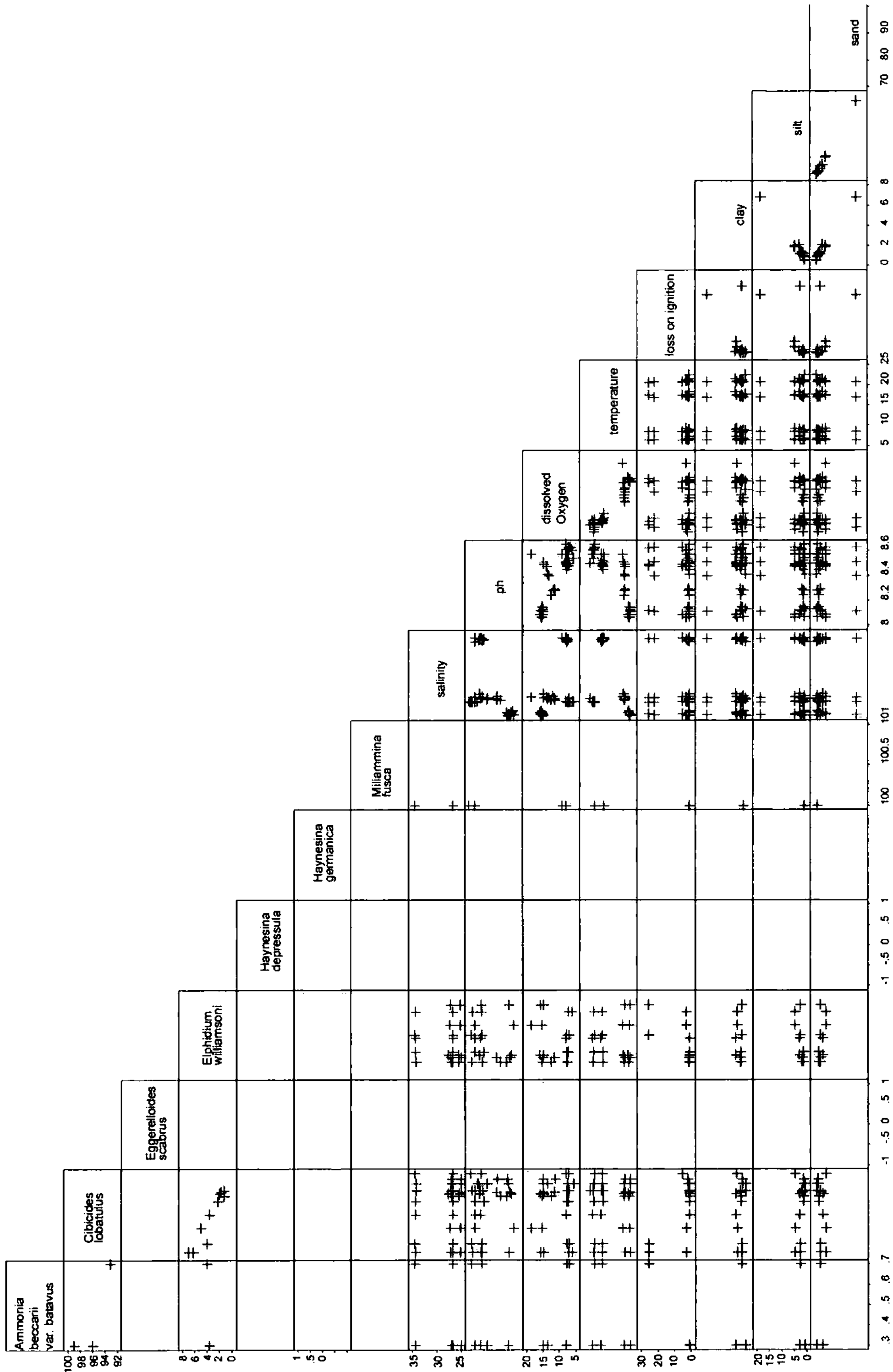


Figure A3.9.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Loch of Reiff, Assynt.

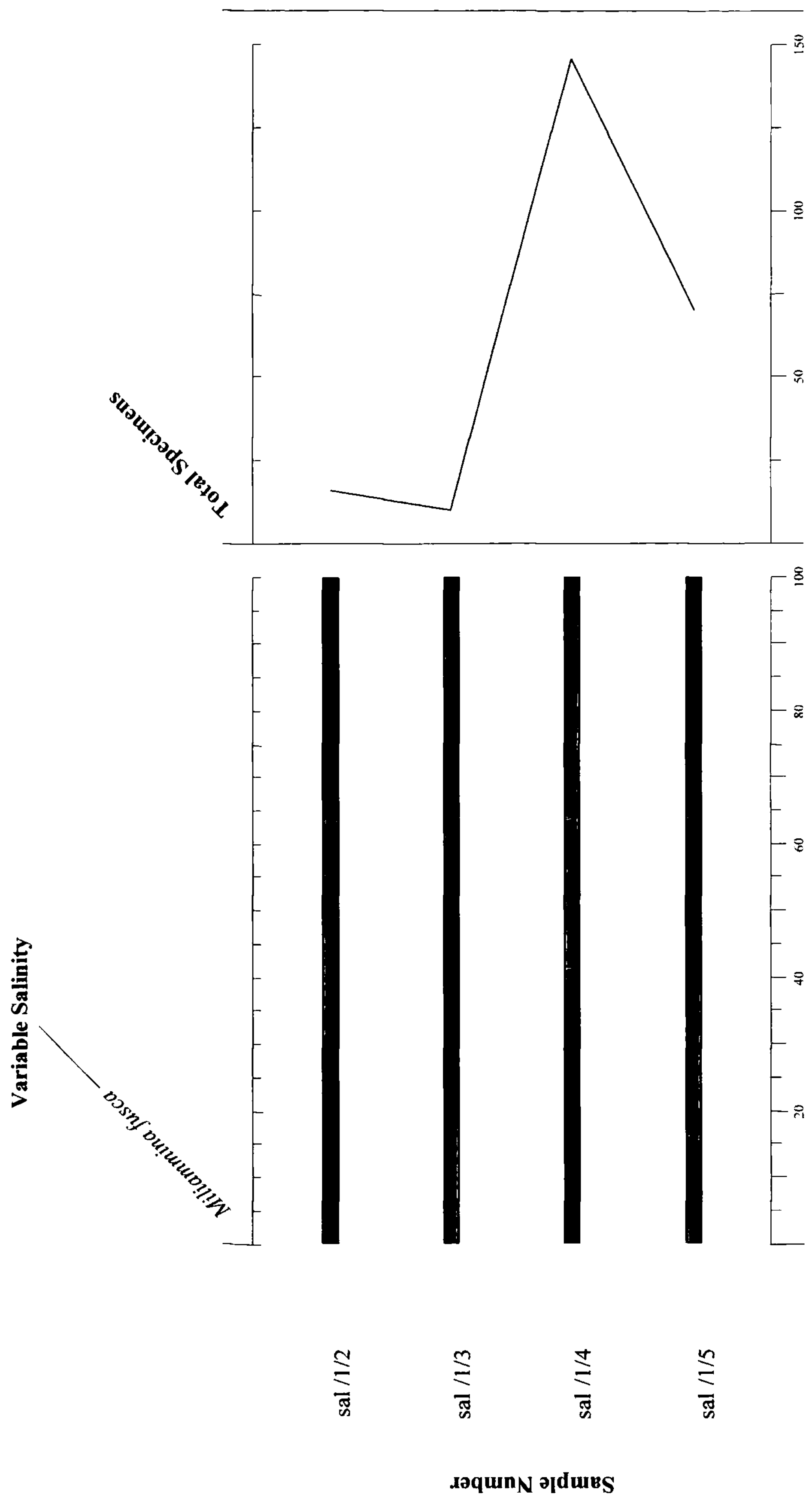


Figure A3.10.1: Foraminiferal assemblages collected from Lochan Sal, Assynt, during April 2000.

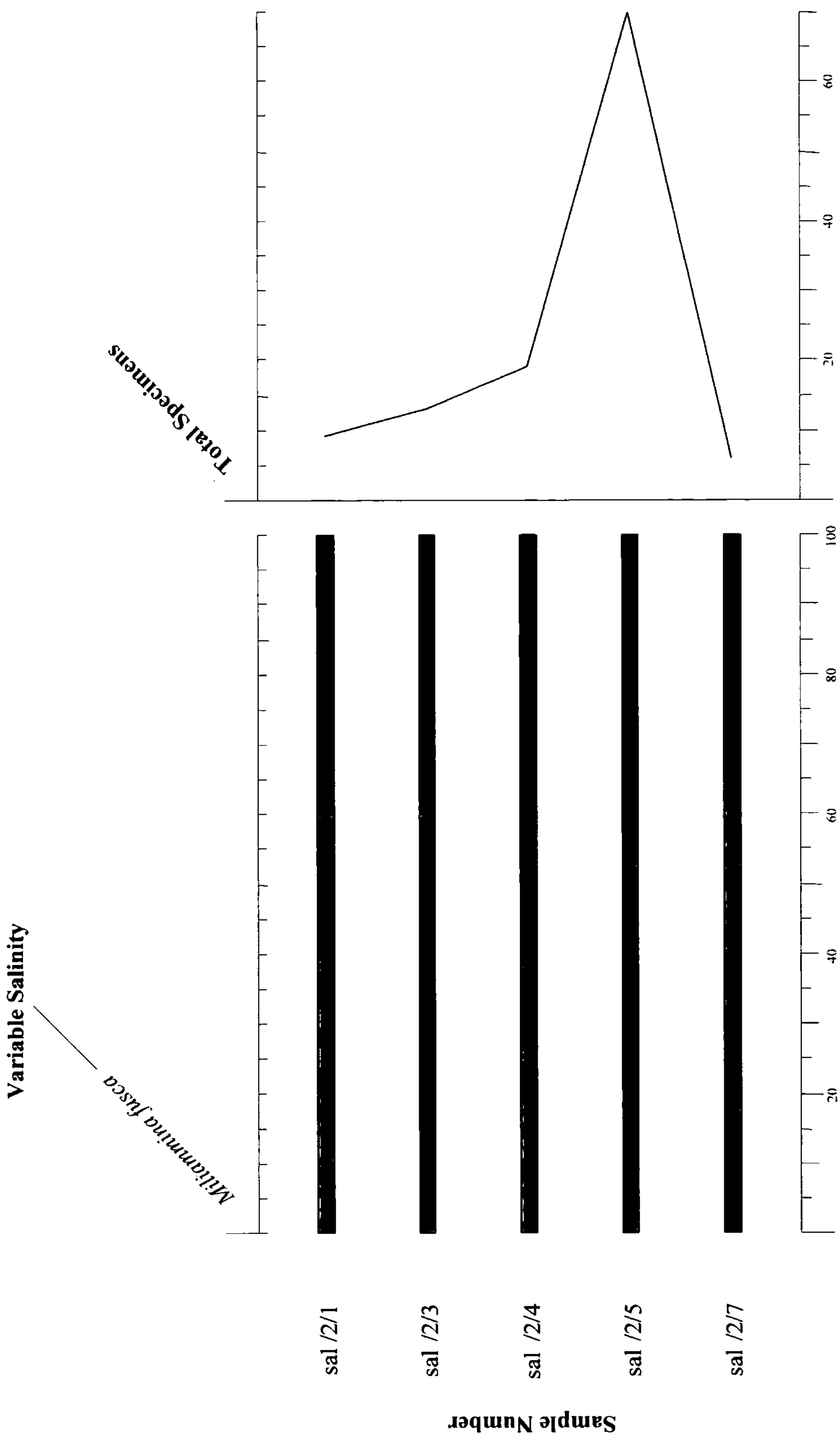


Figure A3.10.2: Foraminiferal assemblages collected from Lochan Sal, Assynt, during August 2000.

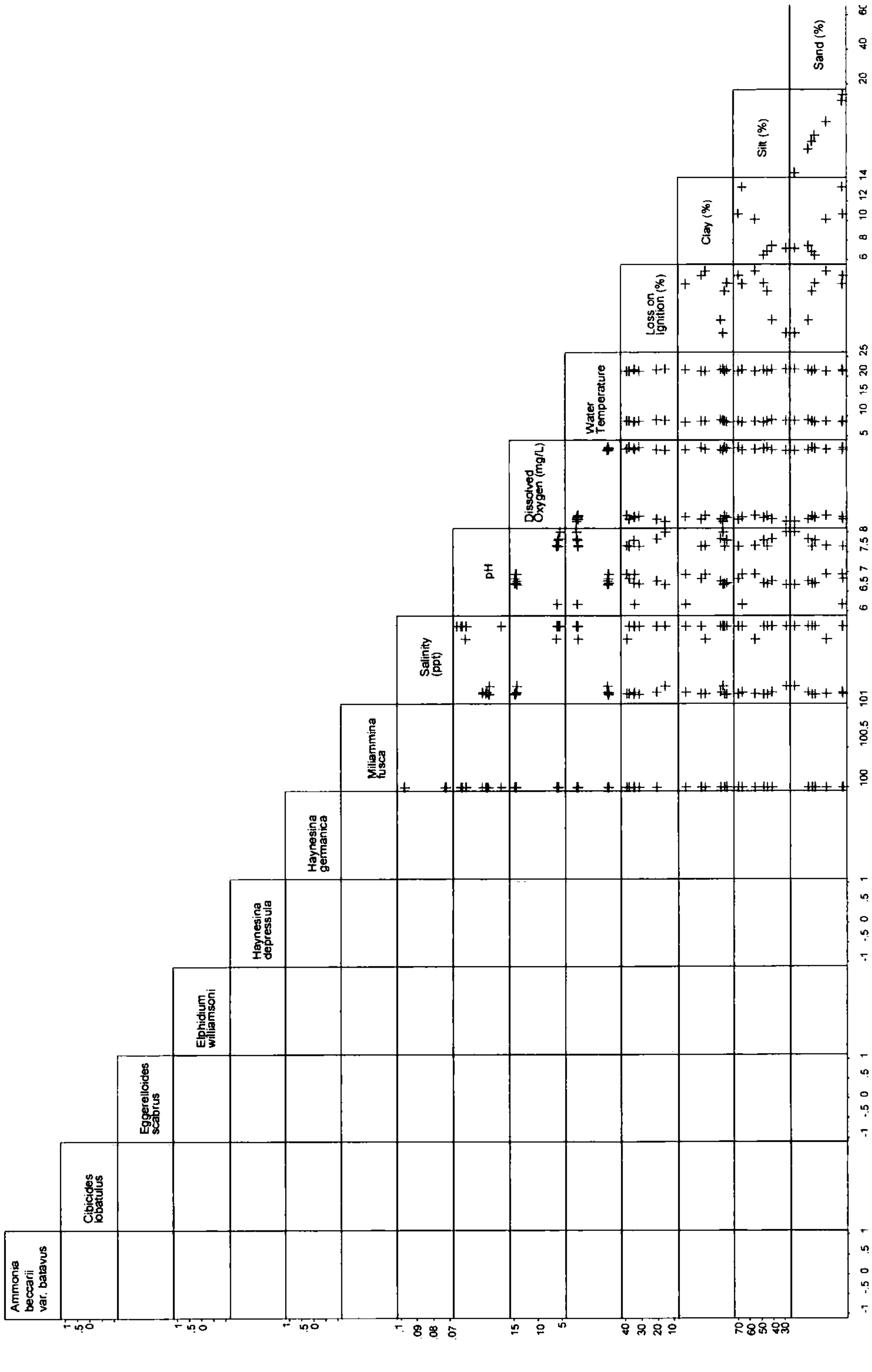


Figure A3.10.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Lochan Sal, Assynt.

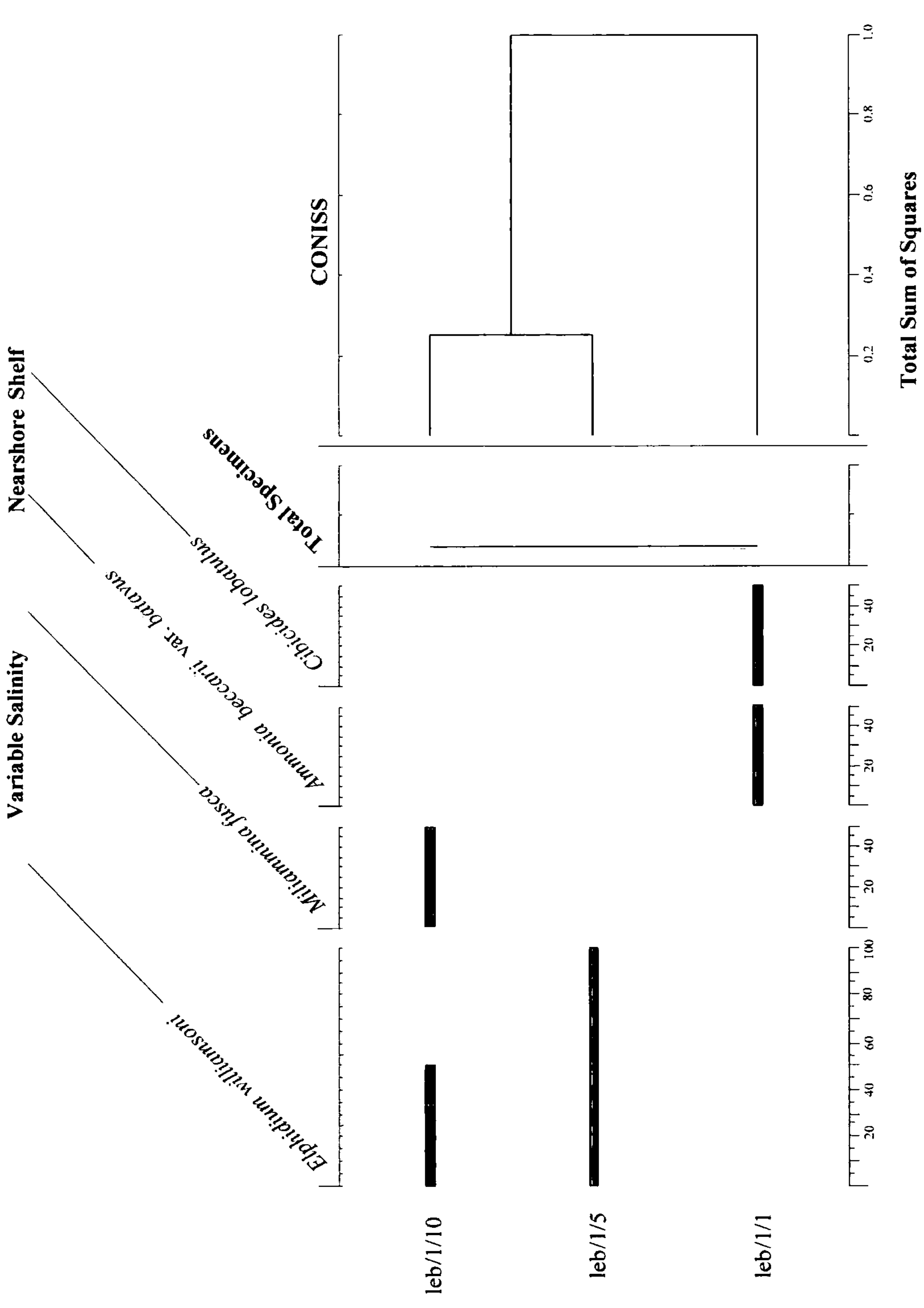


Figure A3.11.1: Foraminiferal assemblages collected from Loch an Eisg-brachaidh, Assynt, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

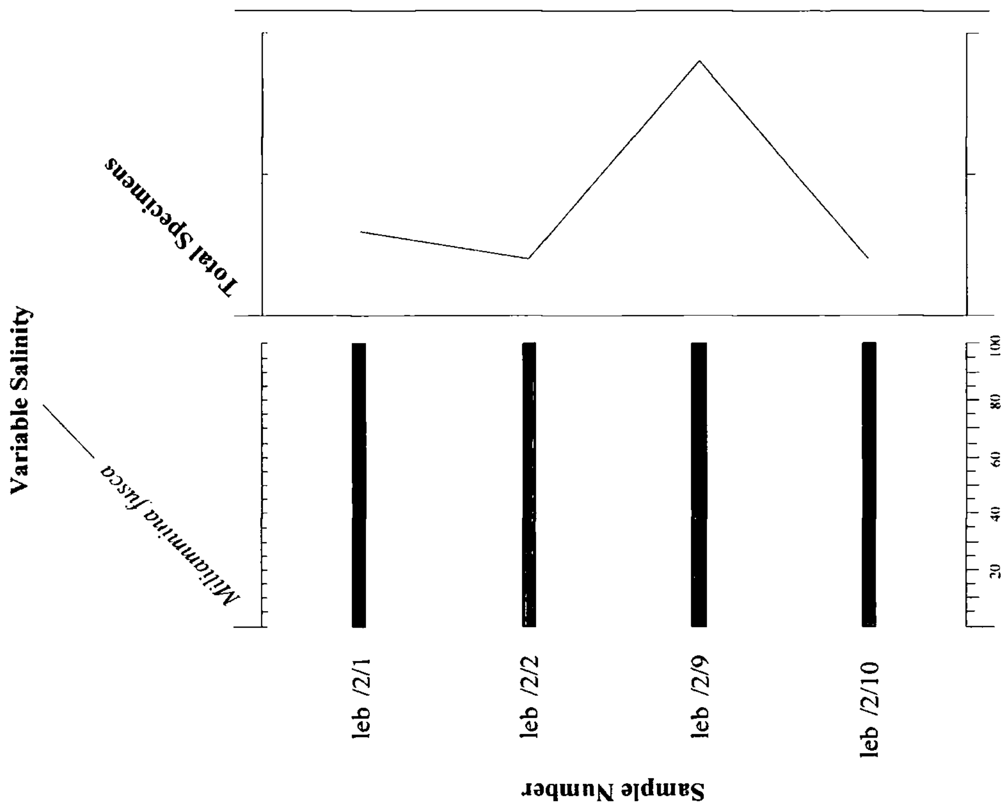


Figure A3.11.2: Foraminiferal assemblages collected from Loch an Eisg-brachaidh, Assynt, during August 2000.

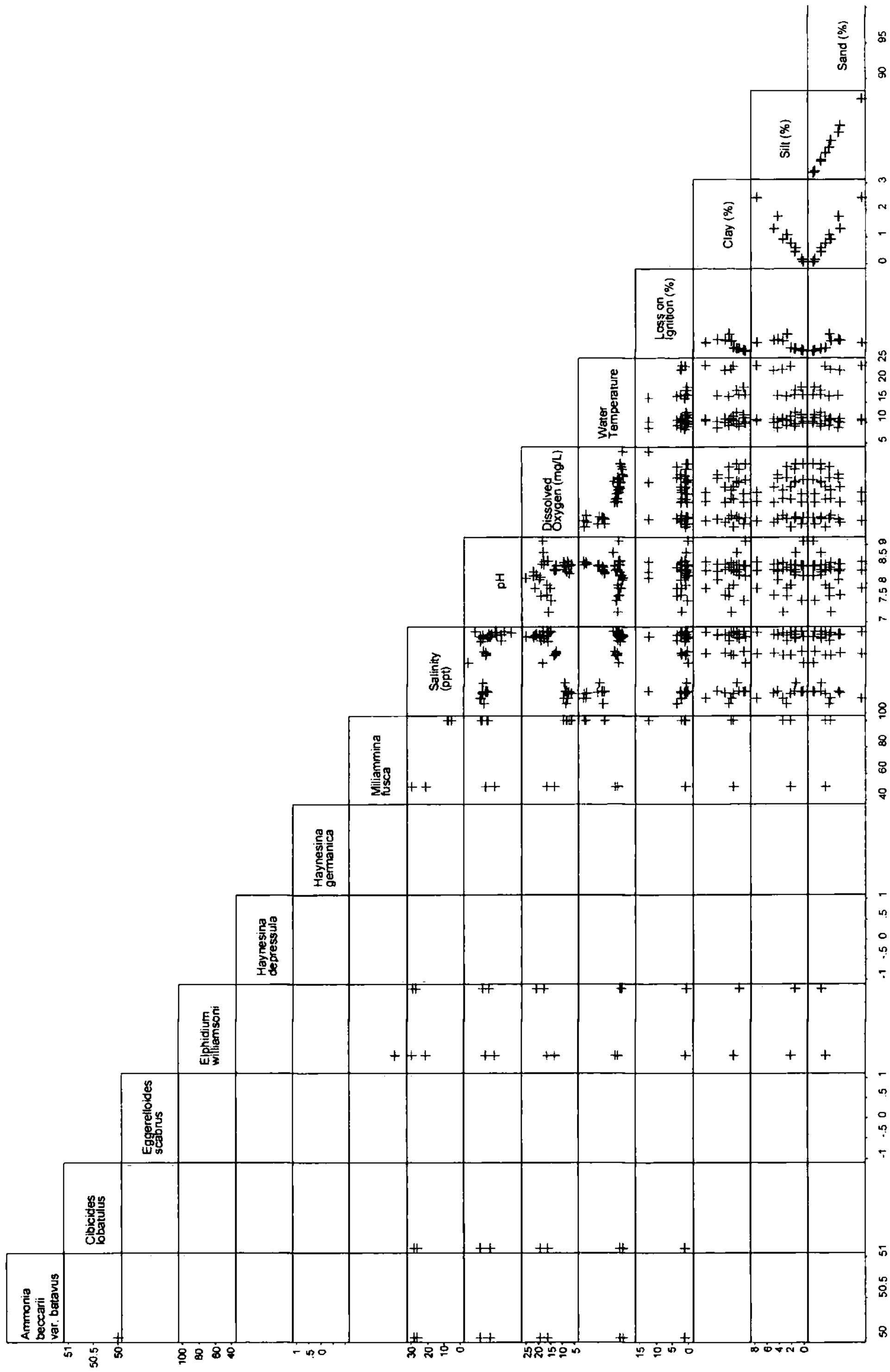


Figure A3.11.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Loch an Eisg-brachaidh, Assynt.

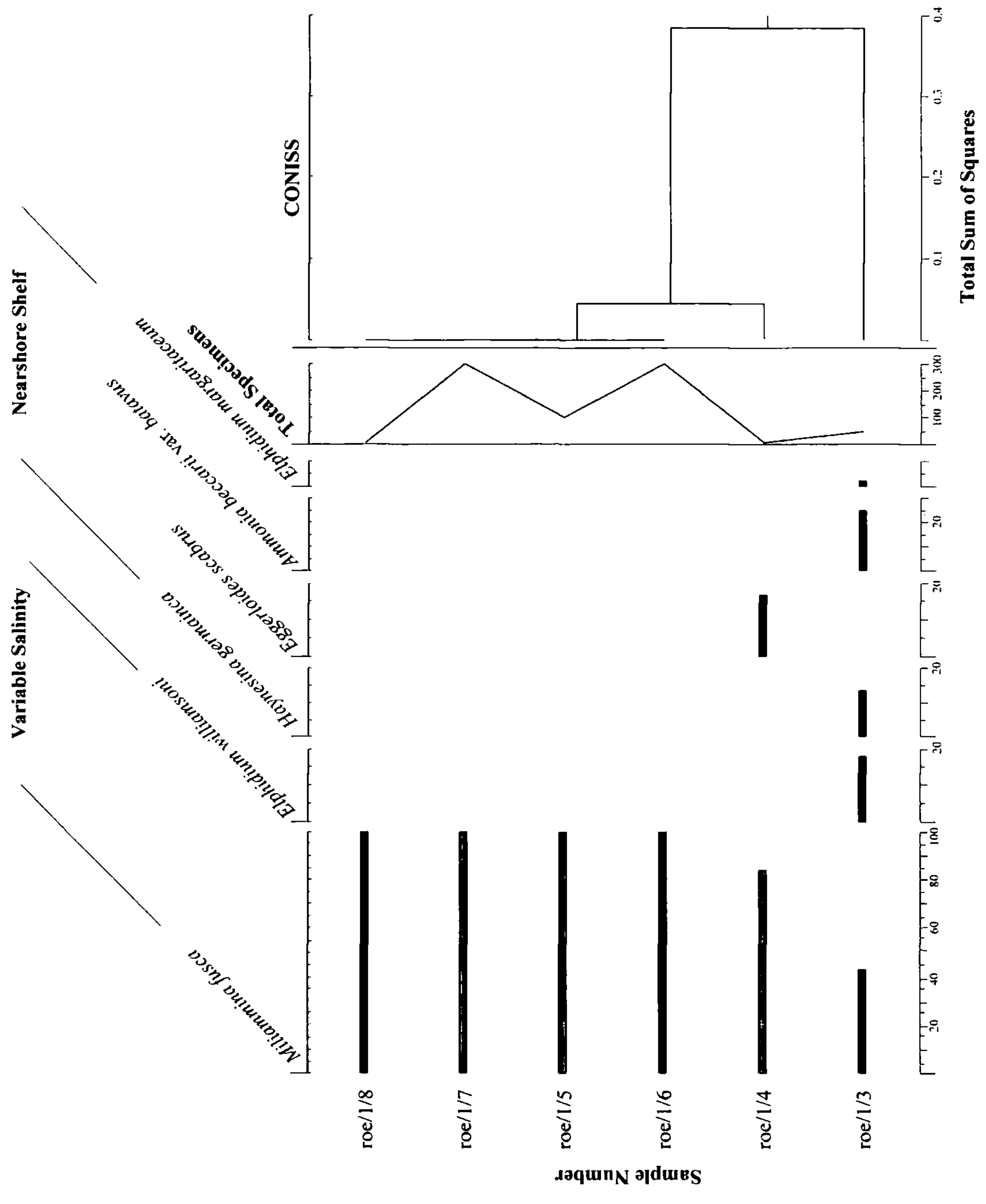


Figure A3.12.1: Foraminiferal assemblages collected from Loch Roe Lagoon, Assynt, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

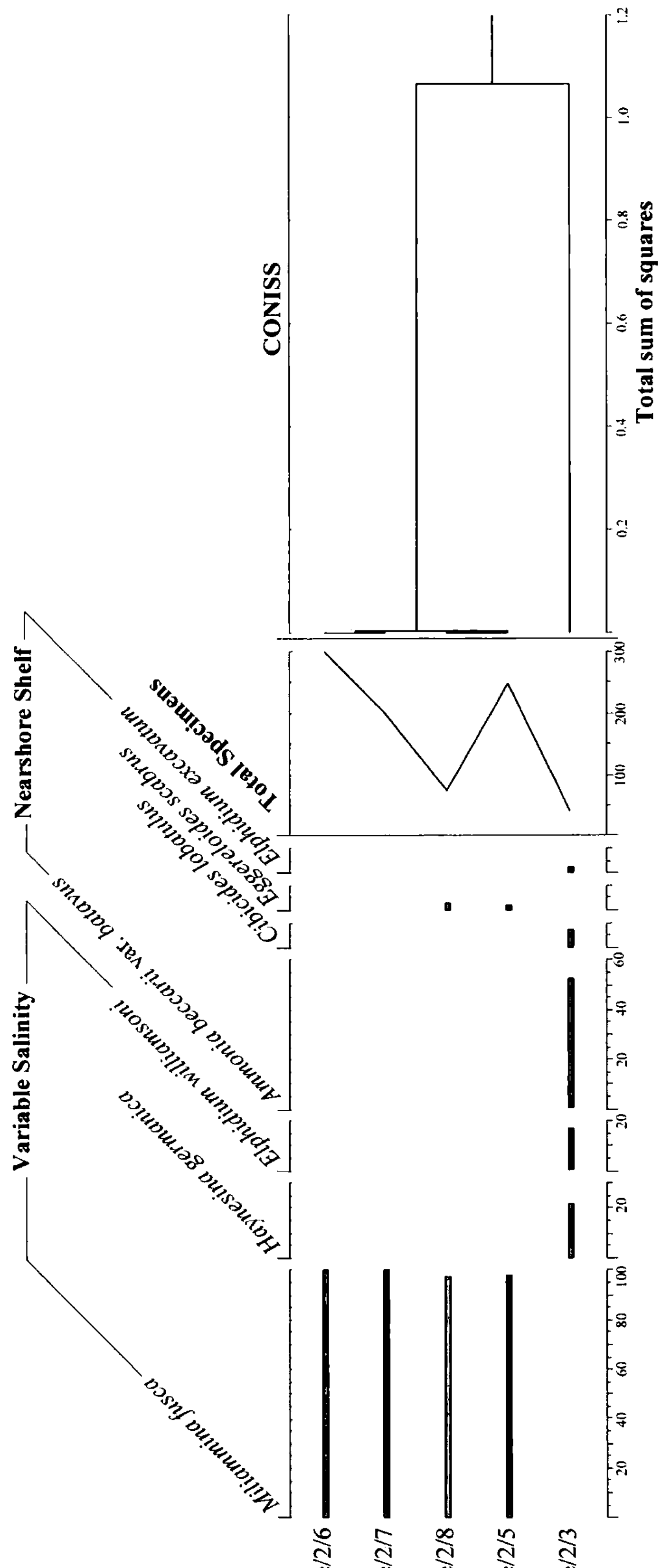


Figure A3.12.2: Foraminiferal assemblages collected from Loch Roe Lagoon, Assynt, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

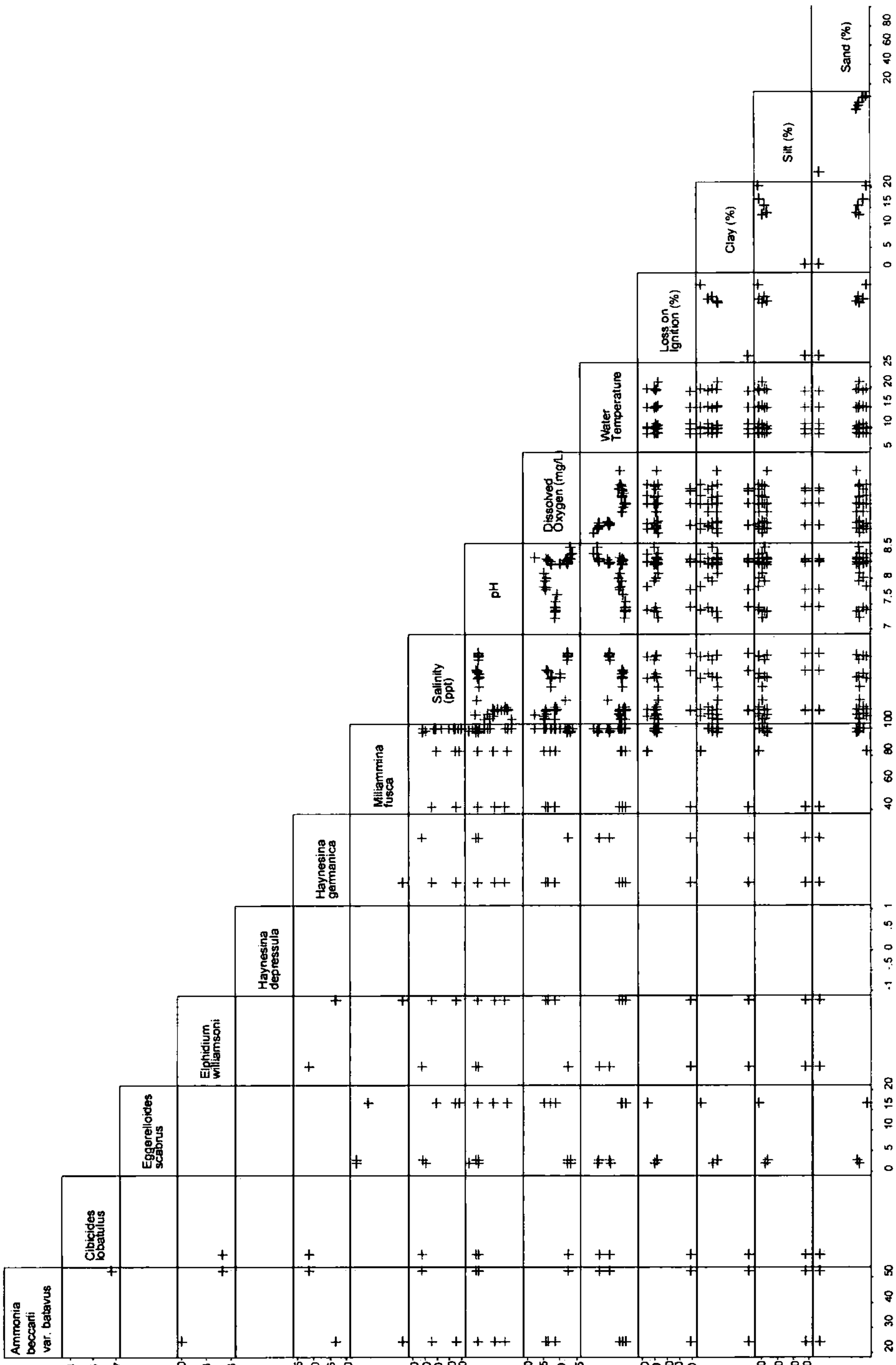


Figure A3.12.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Loch Roe Lagoon, Assynt.

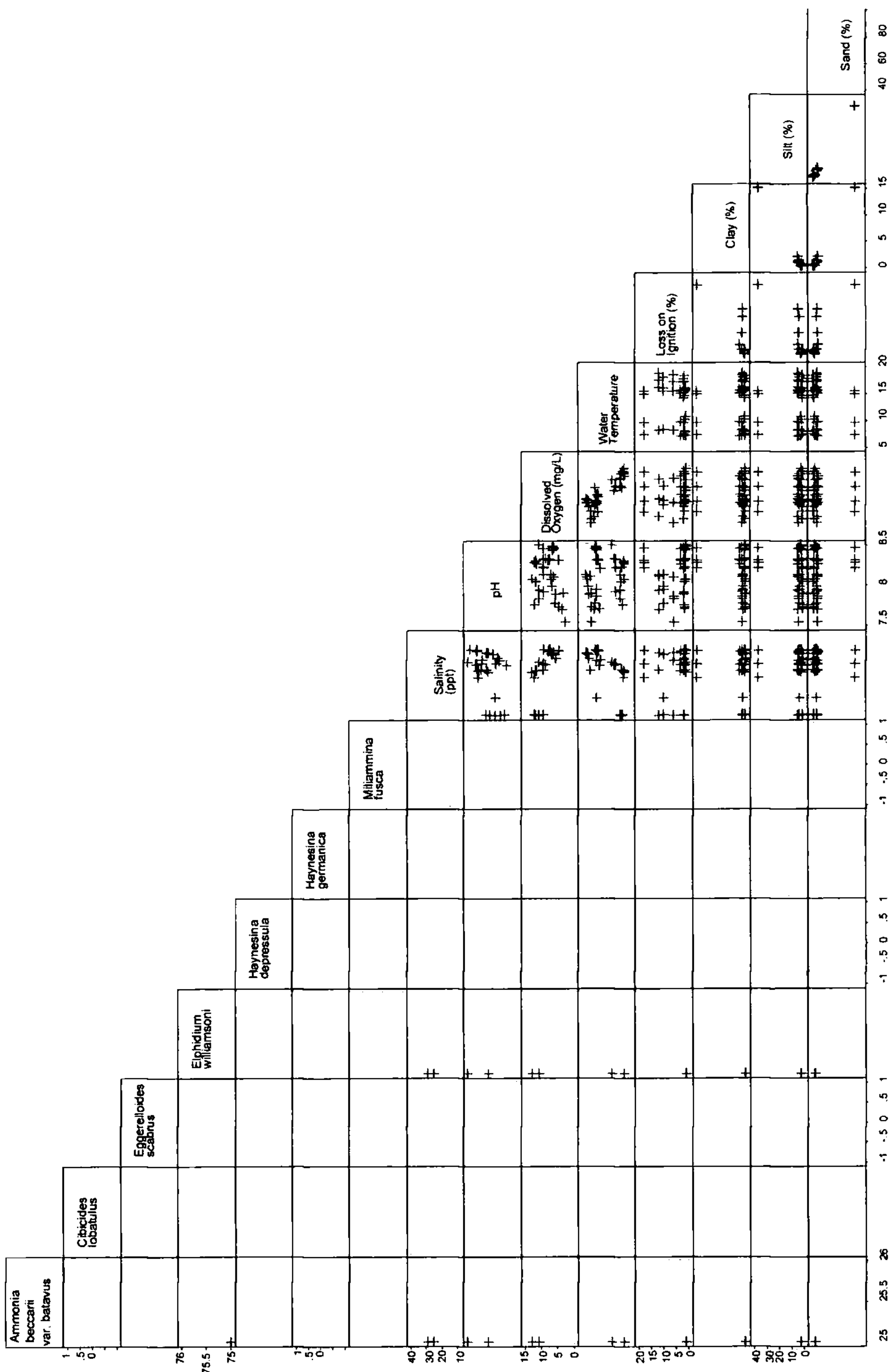


Figure A3.13.1: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Oldany Lagoons, Assynt.

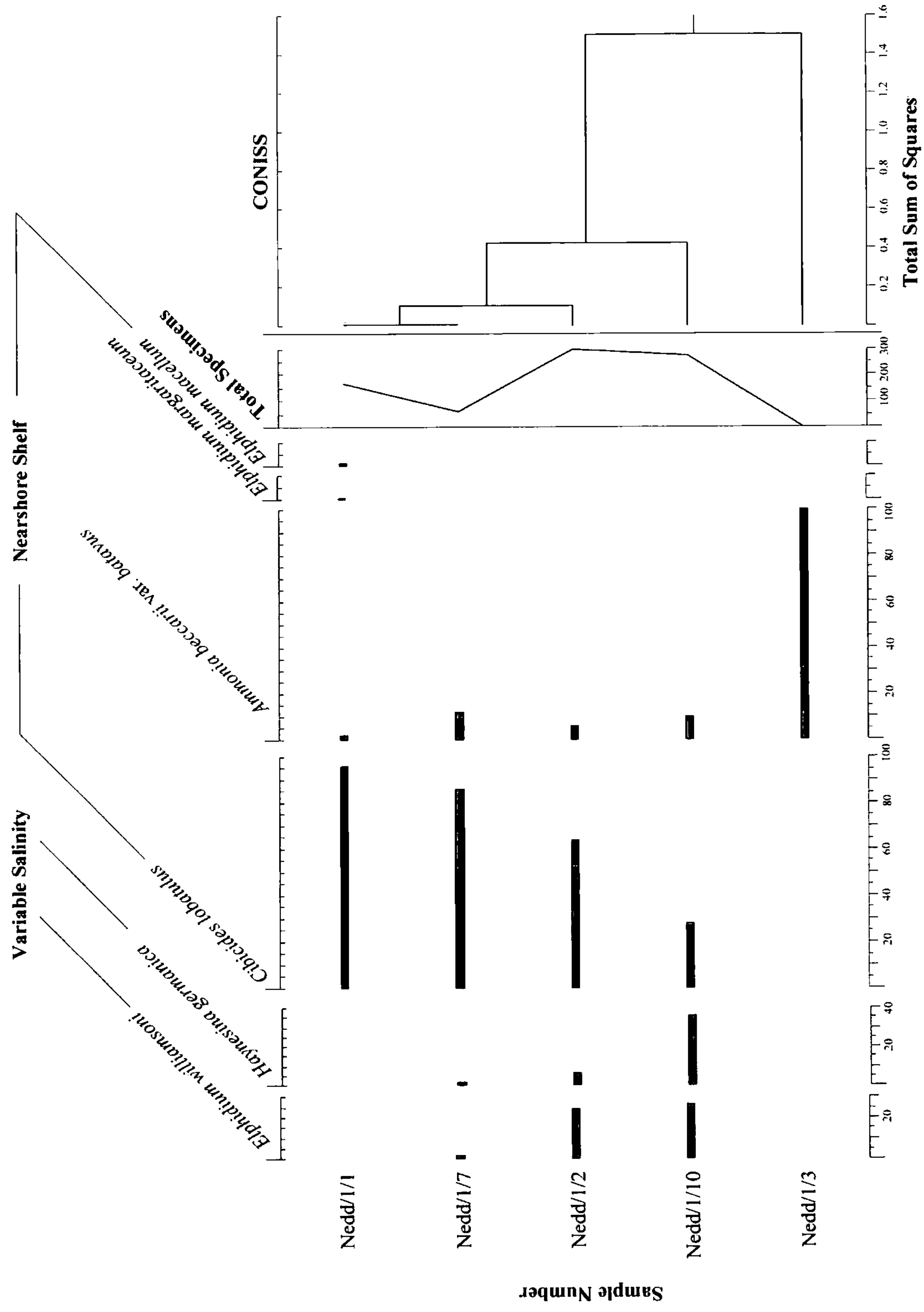


Figure A3.14.1: Foraminiferal assemblages collected from Loch Nedd Lagoon, Assynt, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

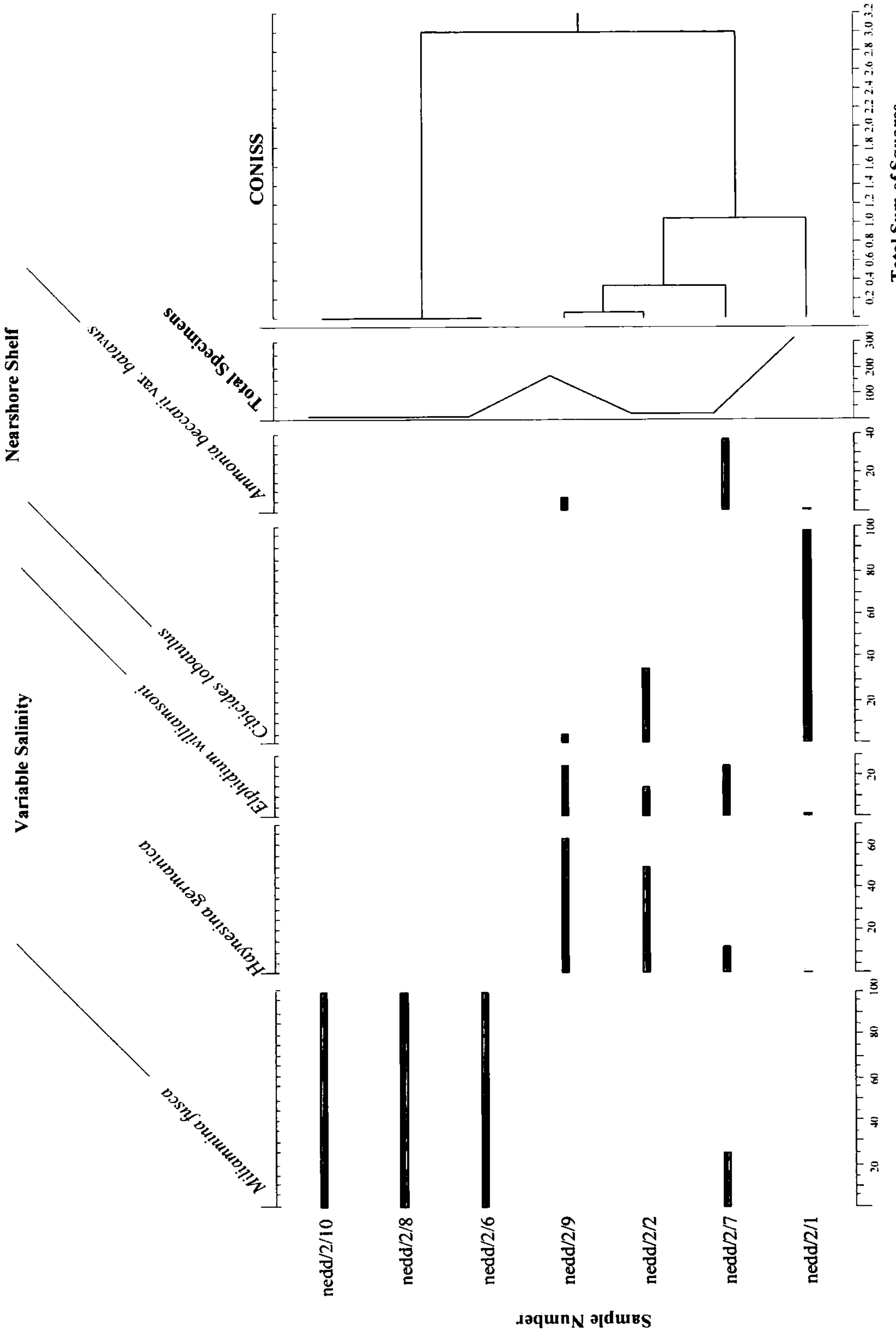


Figure A3.14.2: Foraminiferal assemblages collected from Loch Nedd Lagoon, Assynt, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

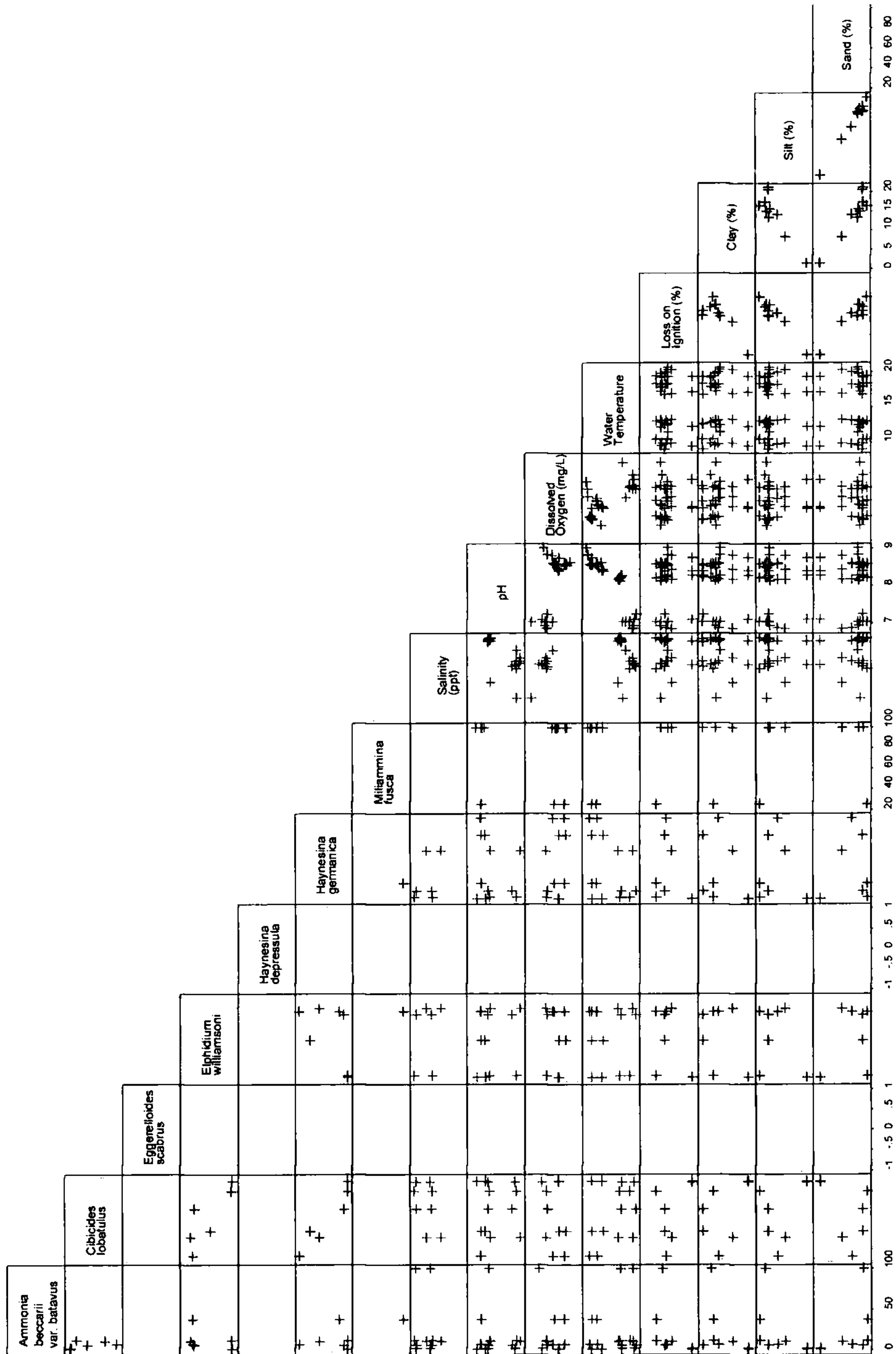


Figure A3.14.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Loch Nedd Lagoon, Assynt.

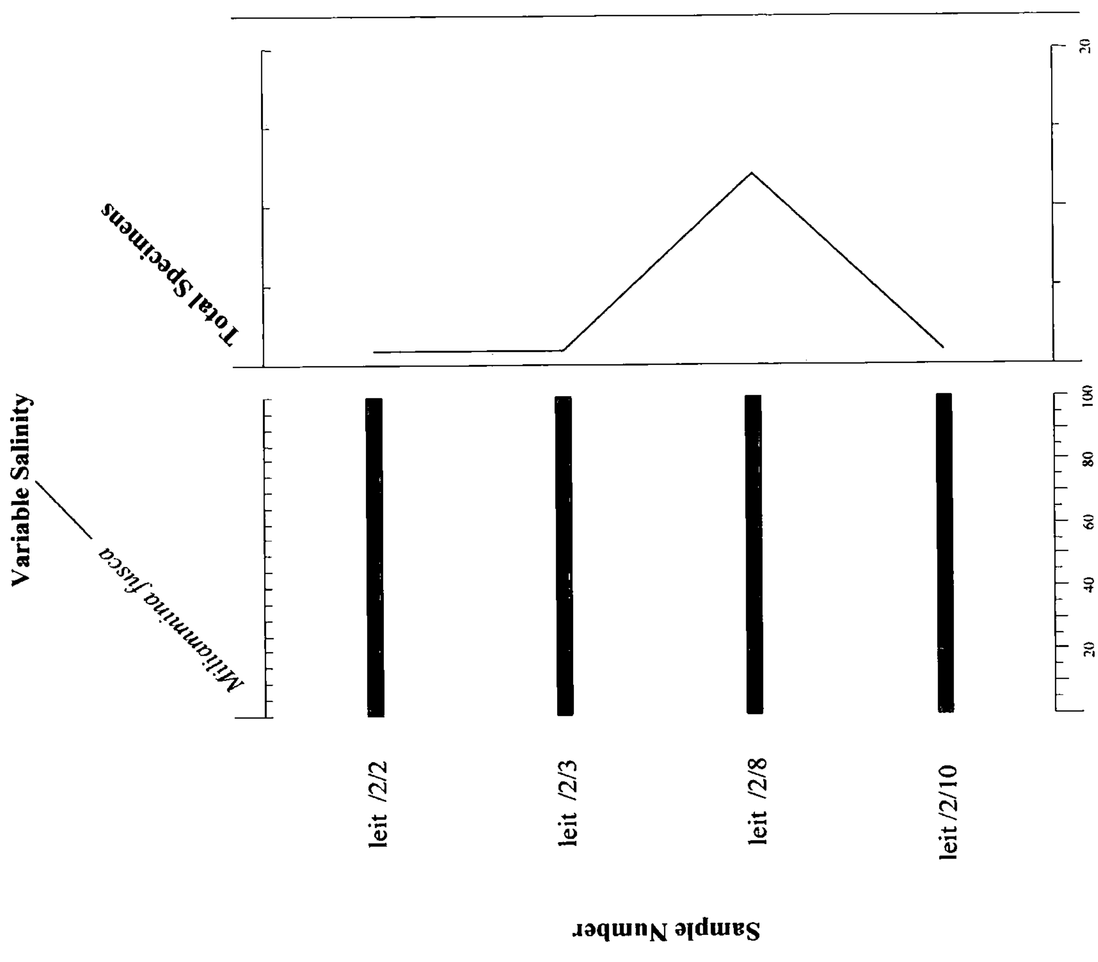


Figure A3.15.1: Foraminiferal assemblages collected from Lochan na Dubh Leitir, Assynt, during August 2000.

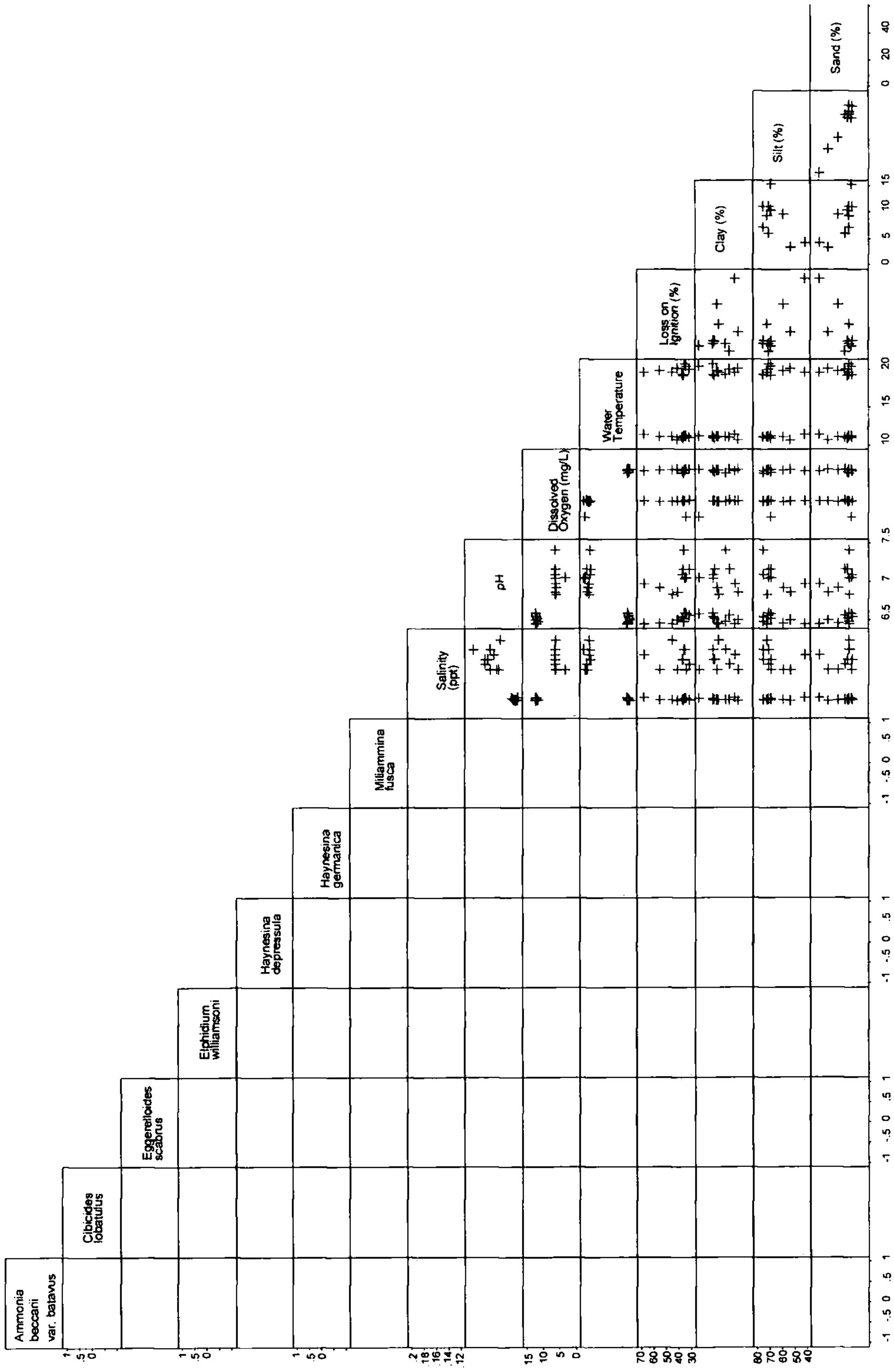


Figure A3.15.2: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Lochan na Dubh Leitir, Assynt.

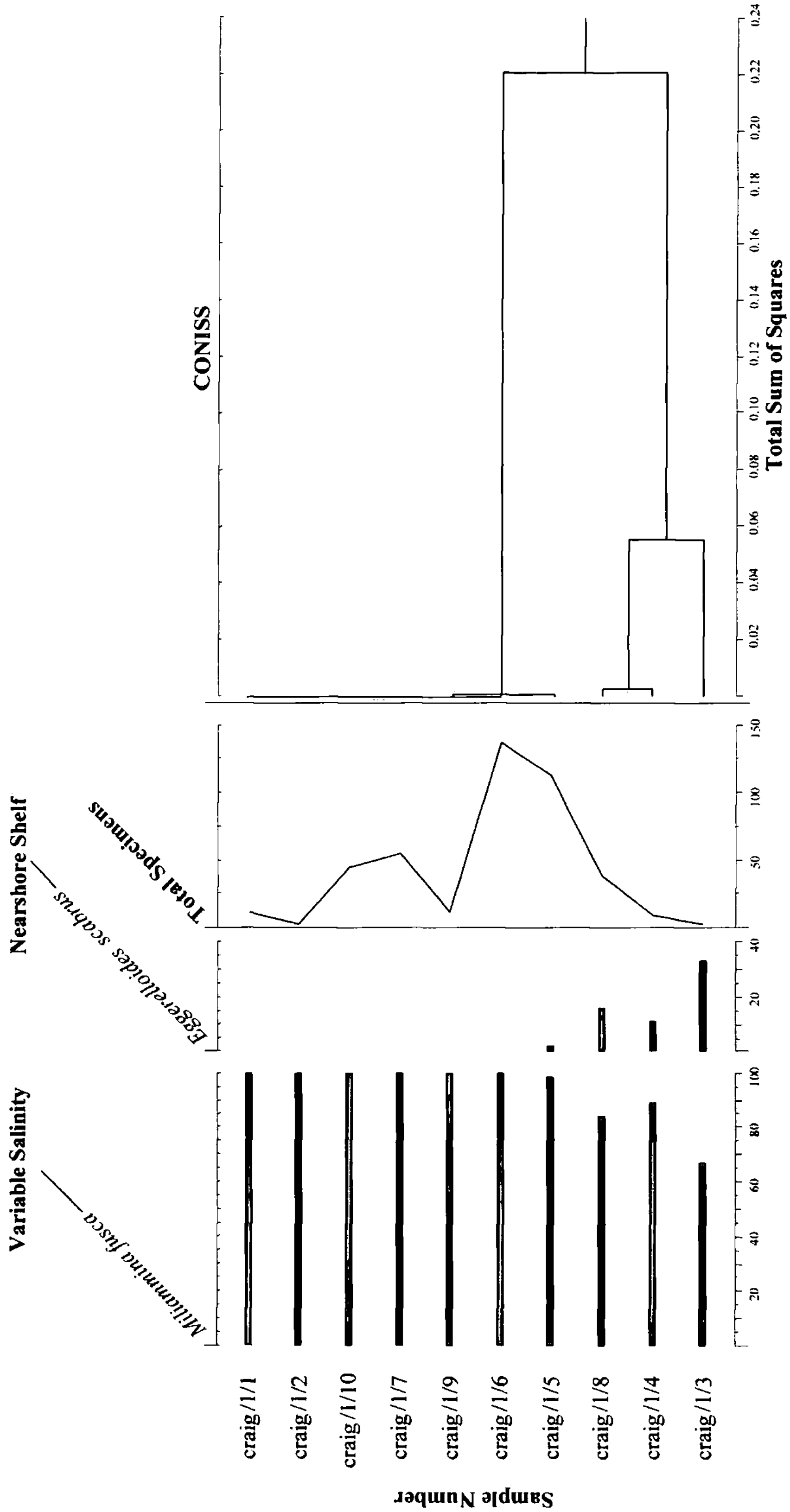


Figure A3.16.1: Foraminiferal assemblages collected from Craiglin Lagoon, Argyll, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

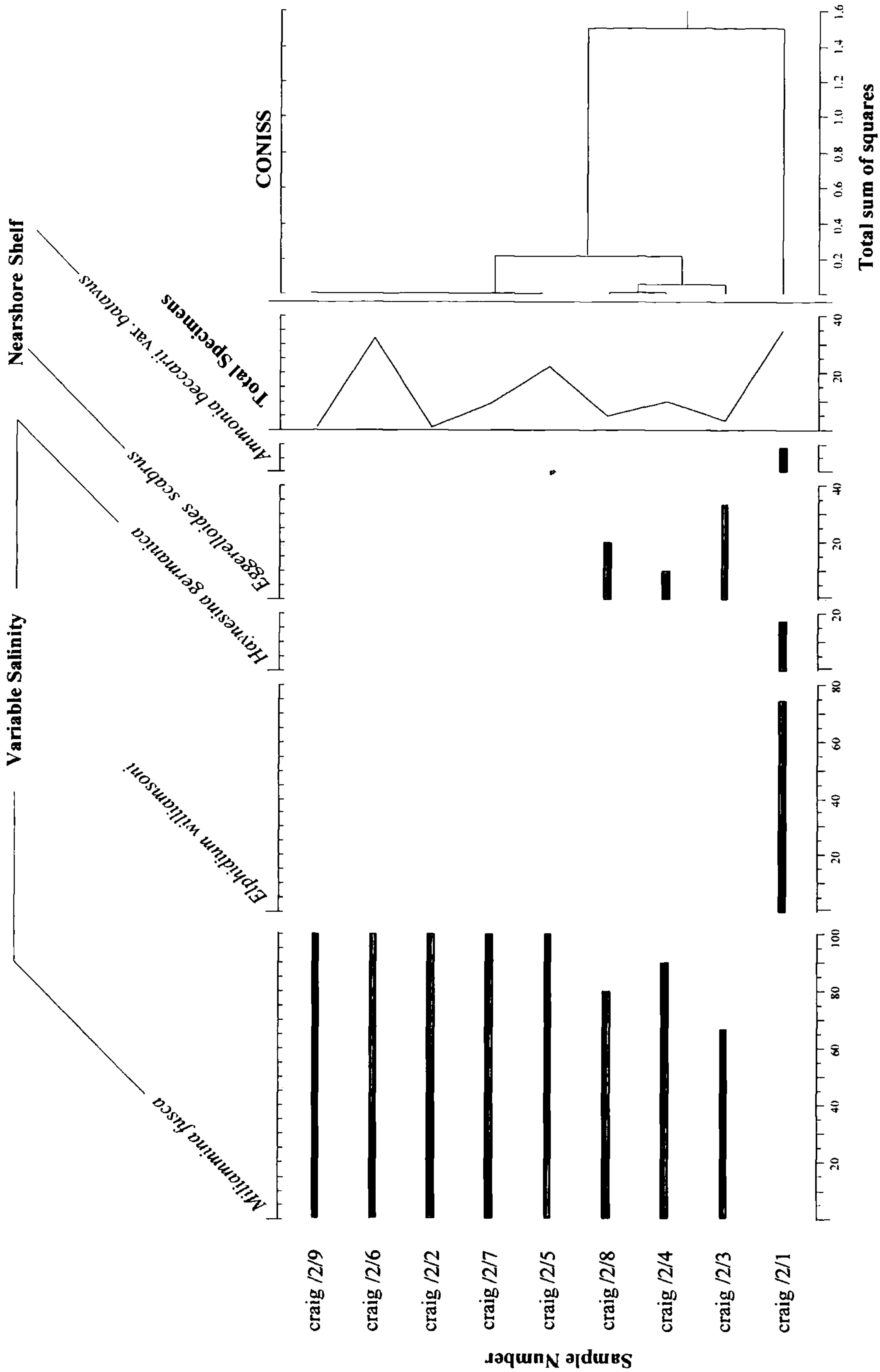


Figure A3.16.2: Foraminiferal assemblages collected from Craiglin Lagoon, Argyll, during August 2000. The CONISS cluster analysis was carried out with no data transformation.

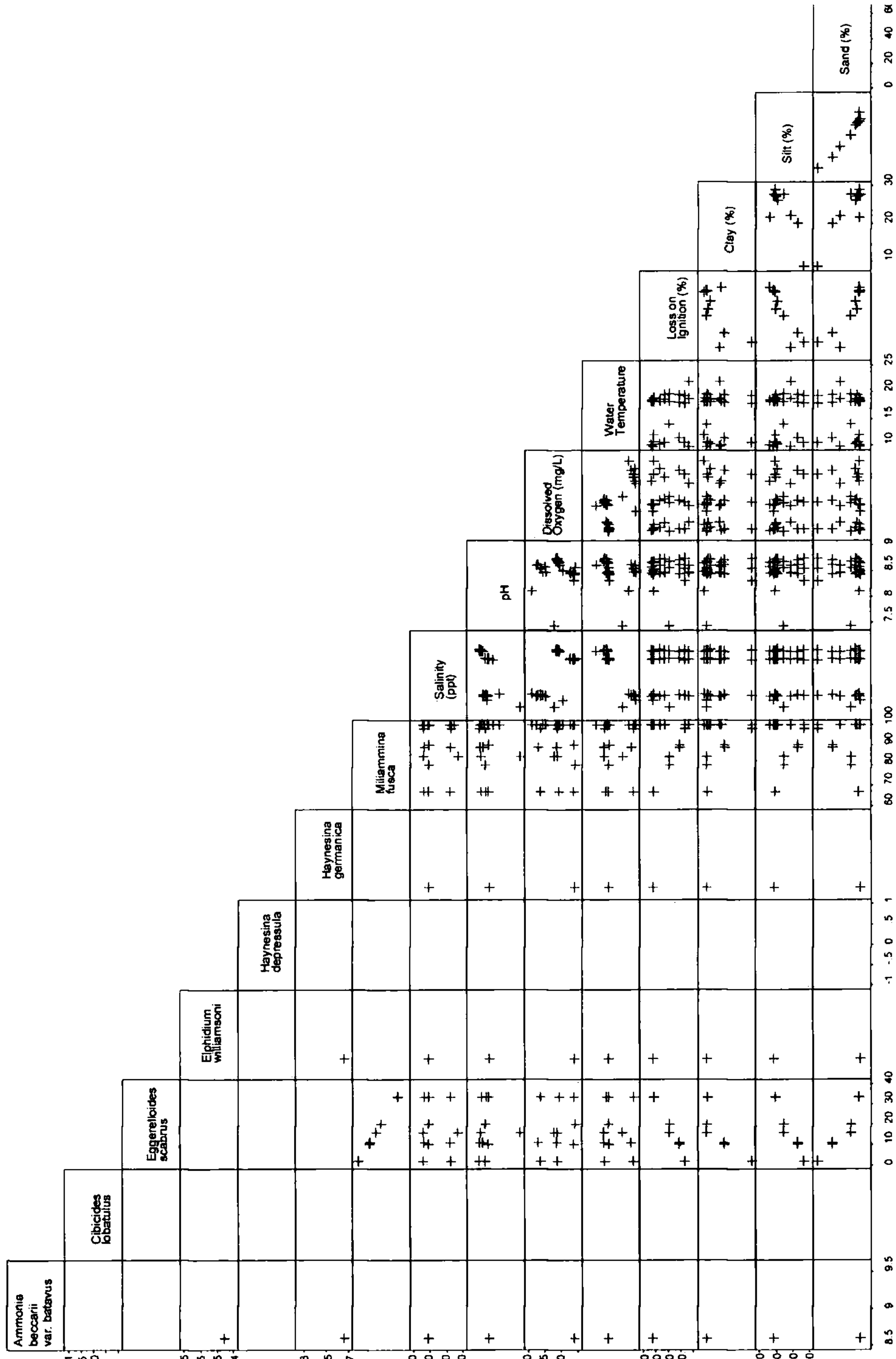


Figure A3.16.3: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Craiglin Lagoon, Argyll.

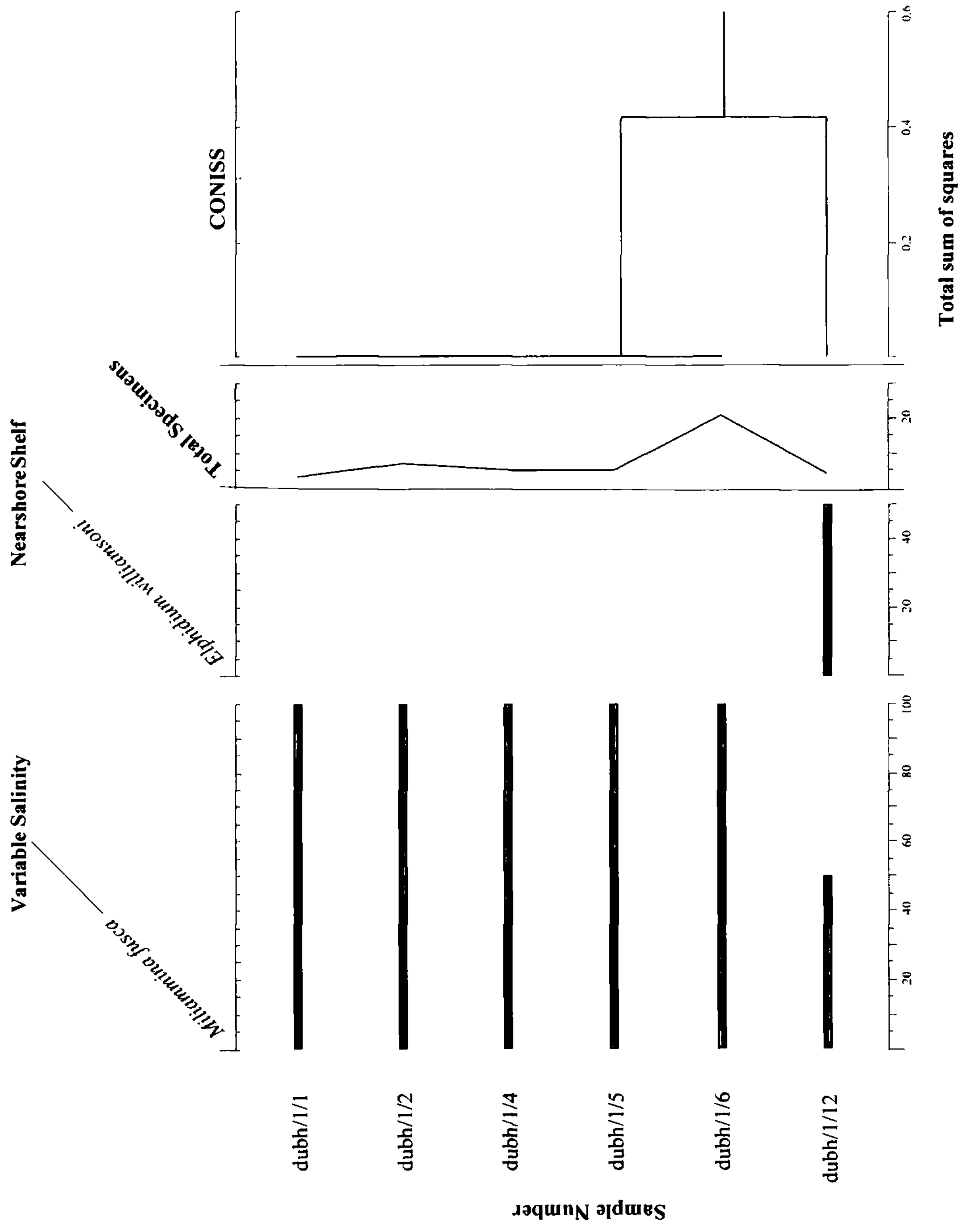


Figure A3.17.1: Foraminiferal assemblages collected from Dubh Loch, Argyll, during April 2000. The CONISS cluster analysis was carried out with no data transformation.

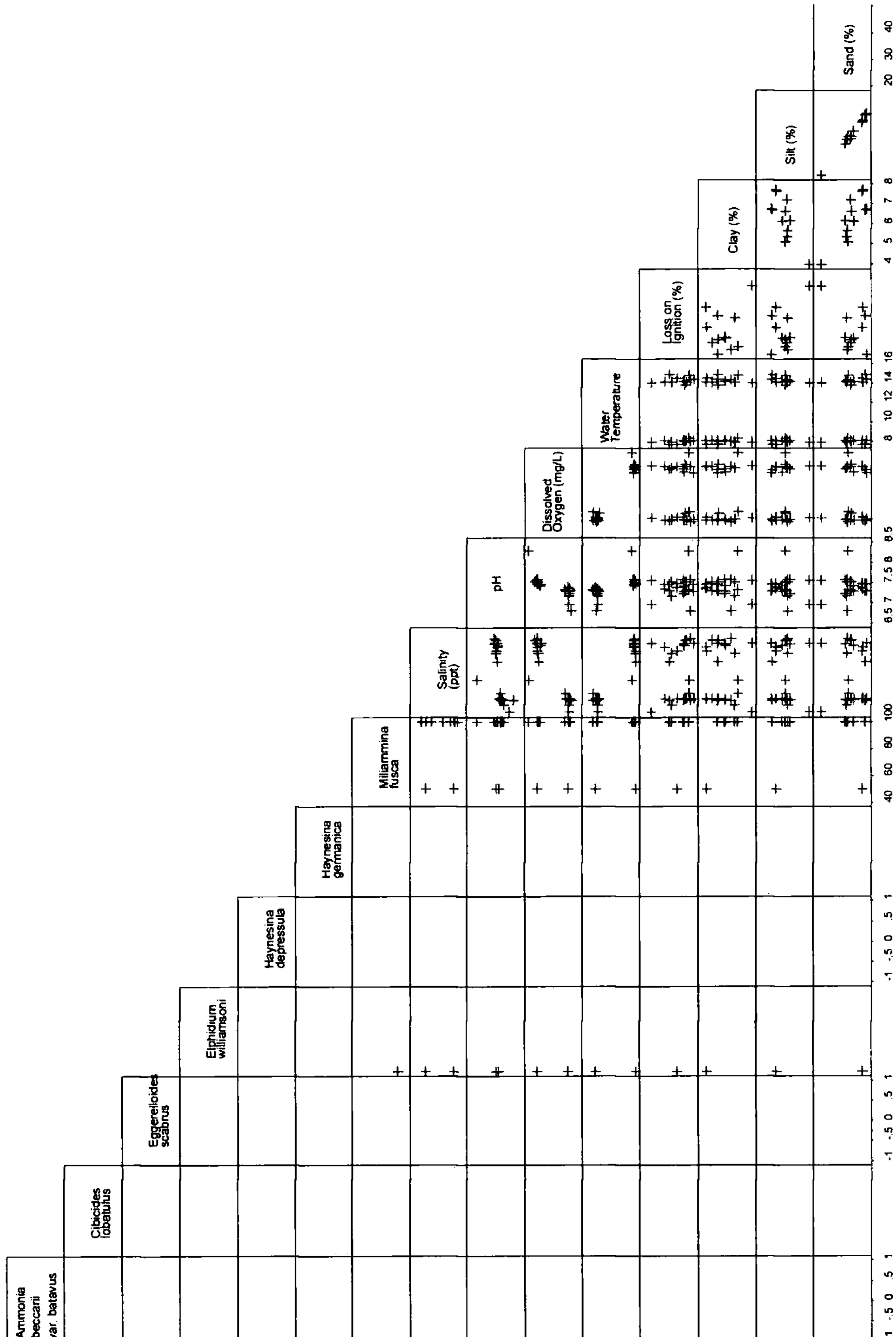


Figure A3.17.2: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships in Dubh Loch, Argyll.

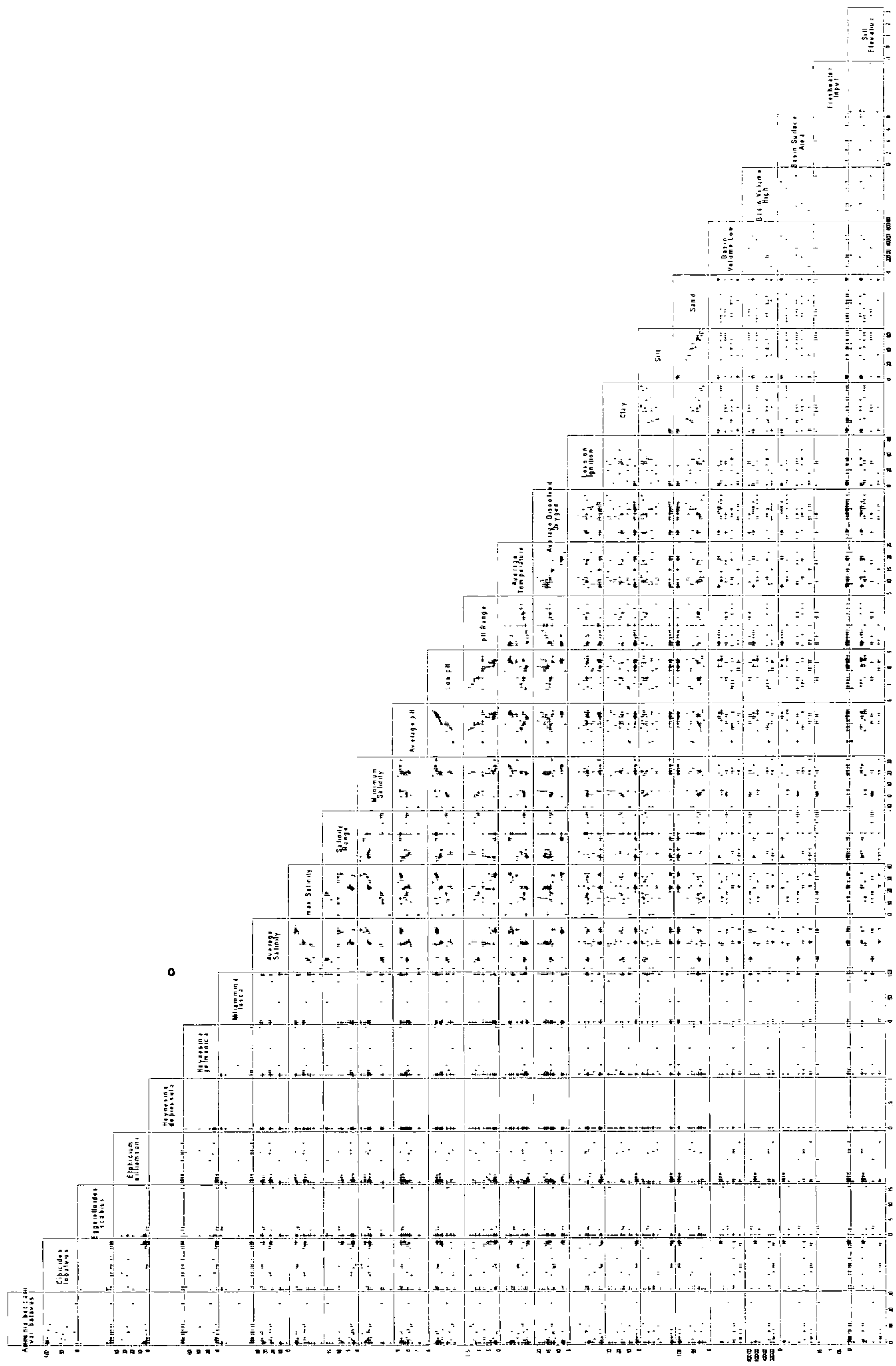


Figure A3.18.1: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships based on the modern dataset for mainland Scotland (Assynt and Argyll)

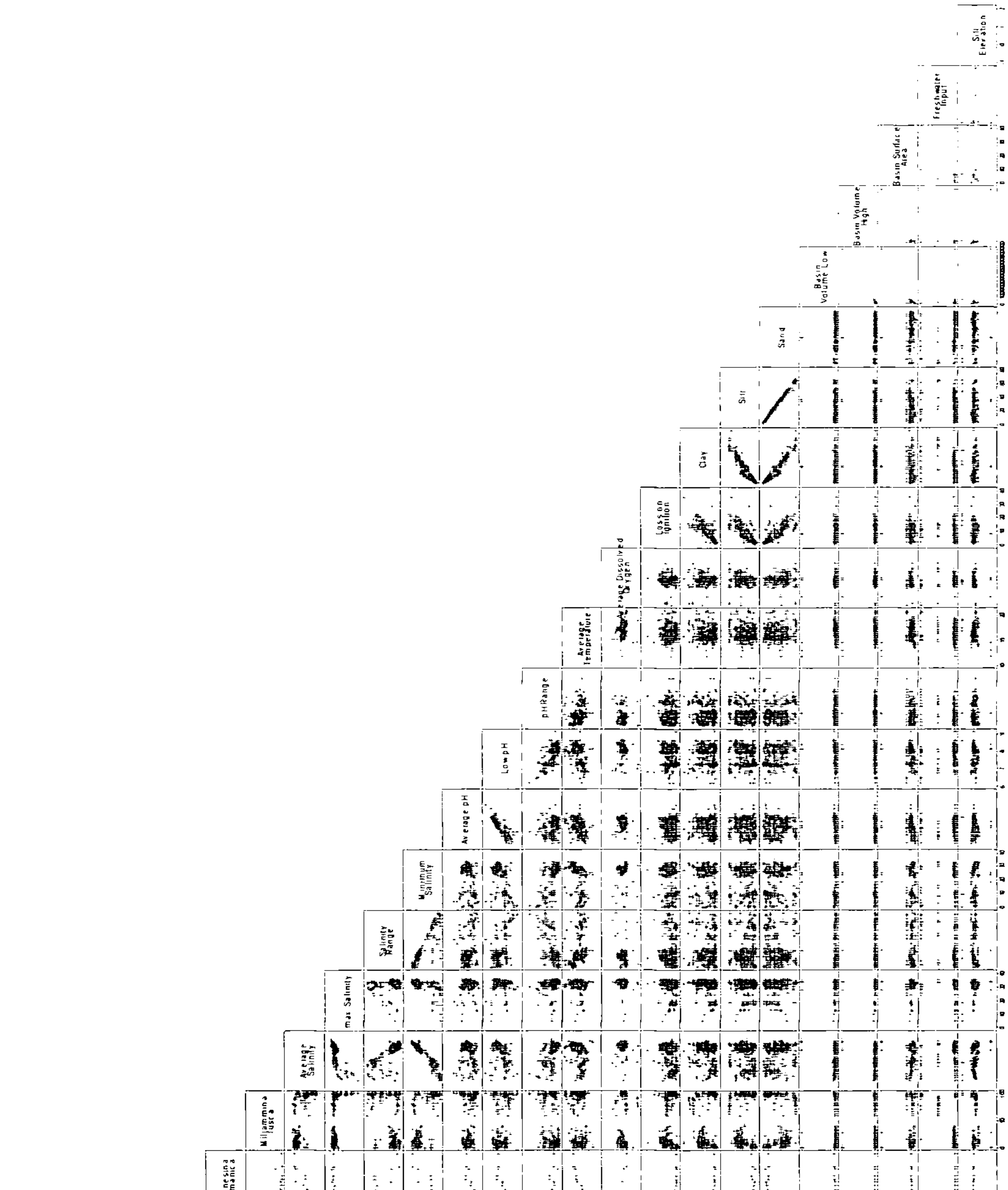


Figure A3.18.2: Scatter plot matrices for foraminifera – environment, environment – environment, and foraminifera – foraminifera relationships based on the modern dataset for the Hebrides (Isles of North Uist and Skye).

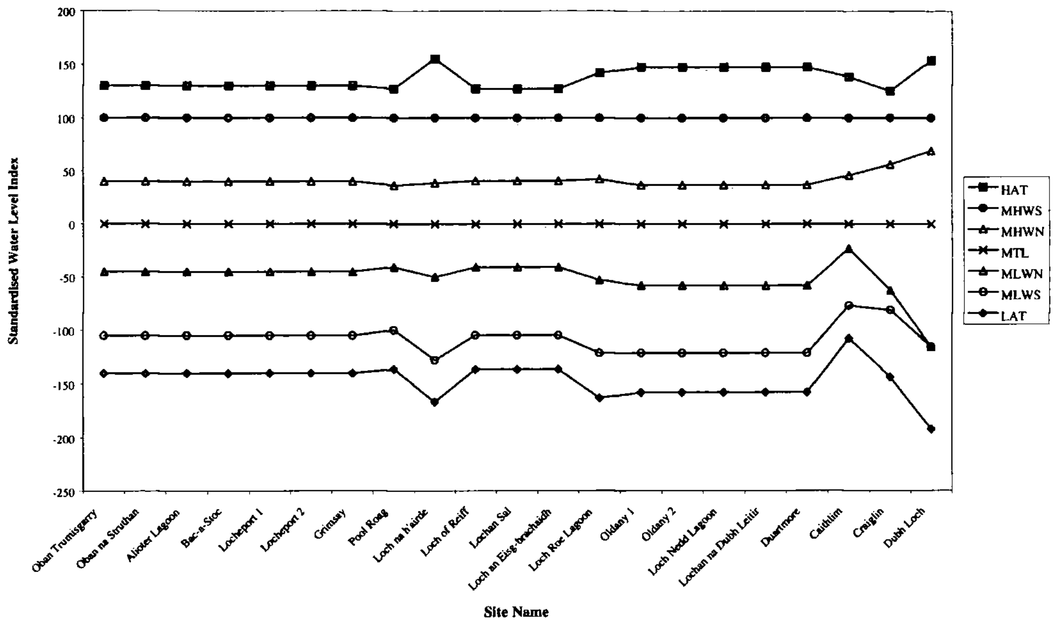


Figure A4.1: Comparison between constructed tide levels for all twenty sites used in this investigation using SWLI Method One.

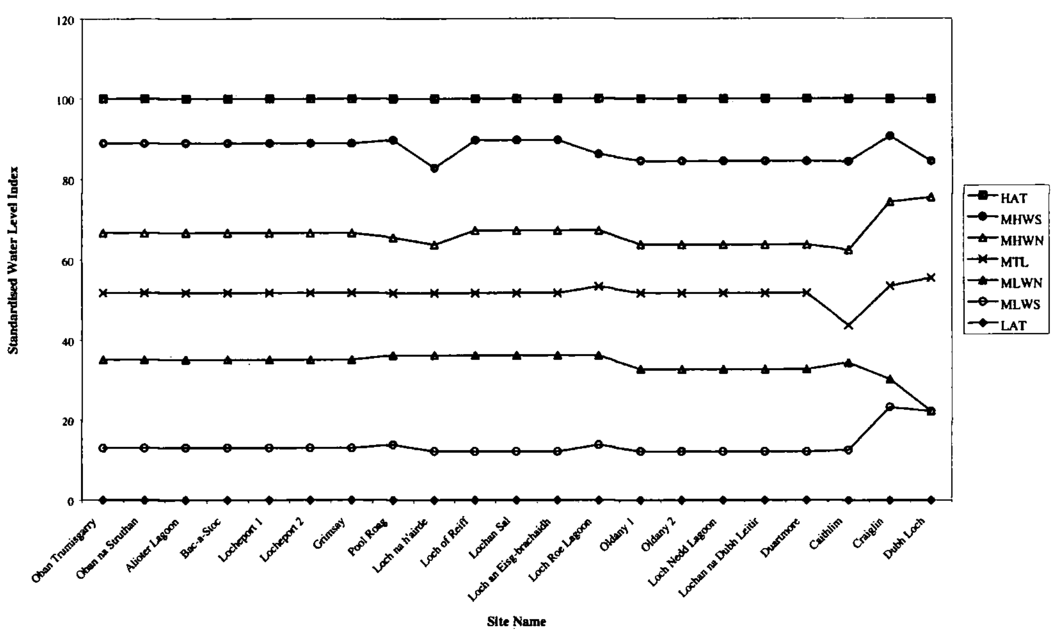
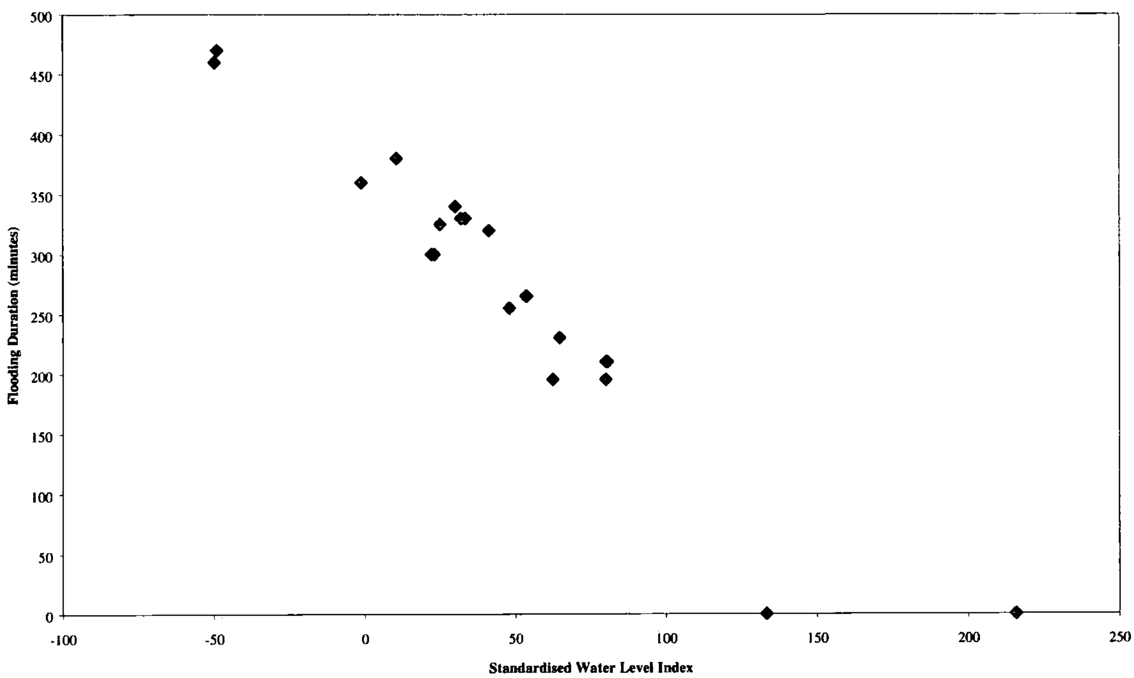


Figure A4.2: Comparison between constructed tide levels for all twenty sites used in this investigation using SWLI Method Two.



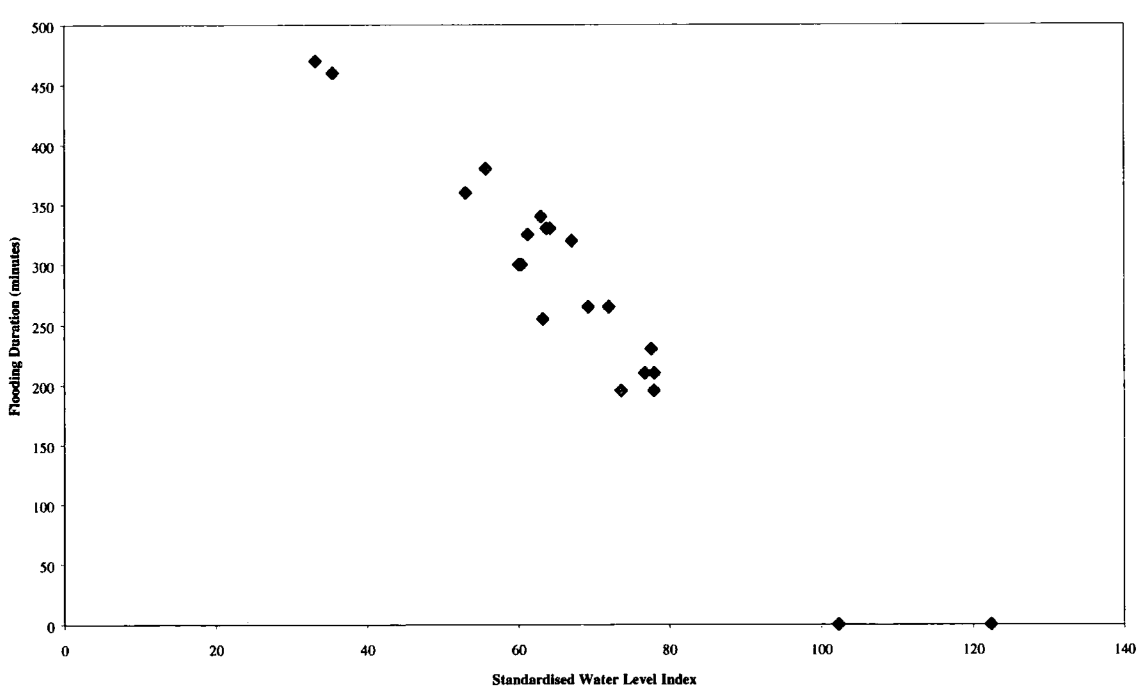


Figure A4.3: Scatter plot of SWLI, calculated using a) Equation One and b) Method Two, versus flooding frequency for all sites. The value of R^2 is a) 0.92 and b) 0.93.

Methods

A1.1 INTRODUCTION

The methods employed in the sampling strategy and data collection stages are described here. This includes the methods used in the analysis of water chemistry, including the calibration of equipment, and sediment properties (loss on ignition and particle size analysis).

A1.2 LABORATORY METHODS

A1.2.1 Salinity

The accurate measurement of salinity within each basin was critical in this research if useful comparisons were to be made between and within sites, and through time.

A1.2.1.1 Calibration

The meters selected for all water chemistry measurements were calibrated on freshly prepared standards, and tested against benchtop meters in the laboratory. The standards were also tested using the Chloride titration method. The Jenway IP67 standard hand-held meter used during the research accepts only one calibration, using KCl (potassium chloride) standards of conductivity strength 1413μS (microsiemens) or 12.88mS (millisiemens) or, in terms of molar strength, 0.01N and 0.1N KCl. The Jenway bench-top meter used in the laboratory allows a three-point calibration, and standards of conductivity 1413μS, 12.88mS, and 24.8mS (0.2N KCl) were used. The hand-held meter was also tested against a self-calibrating YSI 63 meter during the final set of data collection in the field, and the results were within 0.1mS (or mg/L) of each other in water of salinity 27‰.

A1.2.1.2 Measurement

Measurements were taken only once the end-point (meter stabilised) symbol was displayed by the instrument. The conductivity was then converted to salinity using Lab Assistant software v.2.00.05 (PDMS, 1995). One sample from every batch at each site was also tested using the Chloride titration method. These were chosen to represent the full range of salinity values experienced in the field.

A1.2.1.3 Method for Chloride Titration

1. Wearing a lab coat, safety glasses and protective gloves, prepare an N/10 (0.1N) standard of Sodium Chloride (5.845g NaCl in 1 litre of distilled water).

2. Make up an N/10 solution of Silver Nitrate ($AgNo_3$) (17.0g $AgNo_3$ in 1 litre of distilled water). This should be kept in a dark bottle, and stored in a cupboard, in order to prevent the silver nitrate from deteriorating.

3. In a small flask, add 20 – 30ml of distilled water, then add to that 10ml of the NaCl standard, using an automatic pipette or another accurate method.

4. Add 4 or 5 drops of potassium chromate (K_2CrO_4) solution, which will give the sample a yellow colour. In order to ensure that the sample is made acidic, add 2 or 3 drops of Nitric Acid (NHO_3), then a small spatula amount of Calcium Carbonate ($CaCo_3$) in order to make the sample alkaline.

5. Using a 25ml or 50ml burette, mounted on a stand, to add the silver nitrate, first test it against the NaCl standard. Exactly 10ml of silver nitrate should be required to change the colour of the entire sample from yellow to light brown. A magnetic stirrer is useful in mixing the sample, otherwise gently agitate the sample the whole time that silver nitrate is being added.

6. Prepare samples in the same way as the NaCl standard, adding 5 or 10ml to the distilled water, then adding the potassium chromate, Nitric Acid and Calcium Carbonate in turn. If the sample has already been measured using a

conductivity meter, and the conductivity is greater than 10mS, use 5ml of sample. If it has a conductivity less than 10 mS, use 10ml of sample in order to achieve a more accurate result from the reading on the burette.

7. Add the silver nitrate as before.

8. The amount of sample and silver nitrate used in obtaining each reading should be noted and entered into the following equation, where A = amount of silver nitrate used, B = amount of sample used, Y = the figure obtained in the first part of the calculation (required for the second part) and Z = salinity in parts per thousand (‰):

$$Y = (A \times 3.55) \times (1000/B) \quad \textbf{(4)}$$

$$Z = (Y/19350) \times 35 \quad \textbf{(5)}$$

A1.3 Loss on Ignition Analysis

The technique used here is after that of Ball (1964). Approximately 3.5 g of sediment was added to a crucible of known weight, and oven-dried at 105°C for 24 hours. The dried sample was then weighed, and the weight of the crucible subtracted, before being placed in a furnace at 550°C for 4 hours.

Before the ashed samples cool to below 100°C, place them into a dessicator and store them there until they are weighed and, again, the weight of the crucible is subtracted. The percentage difference between the dry weight and ashed weight is the percentage organic content or loss on ignition:

$$\text{Loss on ignition } \% = ((O - I) / O) * 100 \quad \textbf{(6)}$$

Where O is the weight of the dried sample; and I is the ashed weight.

A1.4 Particle Size Analysis

Particle size analysis was carried out using a Coulter laser granulometer, using a minimum of two runs of 90 seconds for each sample. The results were converted to

MS Excel format and simplified into the percentage of material by volume in the clay, silt and sand fractions. The granulometer accepts any particles in the size range 1μm to 2mm (2000μm). The method of sample preparation is as follows

1 Wearing the appropriate safety equipment (lab coat, safety glasses and Nitrile gloves), place approximately 3 g of sediment in a plastic vial. From now onwards, work inside a fume hood

2 Add 20 ml of distilled water and 5 ml of 100 % Hydrogen Peroxide (H_2O_2) to the sample.

3 The sample will effervesce. If this is extreme, allow the sample to settle for a time before covering each tube with foil and placing in a boiling water bath for two hours.

4 Scrape any coarse material which has collected at the top of the tube back down into the sample and, if necessary, add more Hydrogen Peroxide and return to the water bath. Repeat this procedure until all organic material has been dissolved.

5 Centrifuge the samples at 4000 rpm for 4 minutes and carefully decant half of the supernatant liquid off. Top up with water, centrifuge, and decant off the supernatant water.

6 Add 20 ml of distilled water to the tube, then 2 ml of Sodium Hexametaphosphate ($NaPO_3$) solution, which is a deflocculant. The sample is now ready for analysis in the Coulter laser granulometer.

A1.5 FORAMINIFERA

The following procedure is after Scott and Medioli (1980a) and de Rijk (1995).

1 The foraminiferal and, where appropriate, thecamoebian (or testate amoebae) samples are placed in buffered ethanol together with the protein stain rose Bengal (Walton, 1952).

2 Wet sieve through 500μm and 63μm sieves, using light water pressure from a fine spray.

3 Wash the samples into a storage vial with distilled water, add ethanol as a preservative, and store in a refrigerator.

A1.6 LEVELLING SILL ALTITUDES

The majority of sill altitudes were determined using Leica GPS System 300, with the data analysed in the SKI package and tied into the UK Ordnance Survey active GPS network, the data from which is downloadable via the internet.

The maximum error in linking the reference station (in effect a temporary benchmark) to the active network was less than 25 mm. Given that the errors associated with the (no longer maintained) UK benchmark system are up to order of magnitude larger than this, 25mm can be accepted as a legitimate error margin.

Added to this are any differences between the reference station and the rover station used at each site. The quality of this solution never exceeds 41 mm, although more typical error values are sub-millimetre.

For the small number of sites where the GPS equipment was not available, a Leica Total Station was used, in conjunction with the OS benchmark system. In order to maximise the accuracy of this system, the benchmarks used were cut in solid rock and all transects were closed back to the benchmark, with a maximum accepted closure error of 50mm.

Foraminiferal Species List

Ammonia beccarii var. *batavus* (Hofker)

Ammoscalaria runiana (Heron-Allen and Earland)

Cibicides lobatulus (Walker and Jacob)

Eggerelloides scabrus (Haynes)

Elphidium excavatum (Terquem)

Elphidium macellum (Fichtel and Moll)

Elphidium margaritaceum (Cushman)

Elphidium williamsoni (Haynes)

Haynesina depressula (Walker and Jacob)

Haynesina germanica (Ehrenberg)

Jadammina macrescens (Brady)

Miliammina fusca (Brady)

Quinqueloculina spp.

Trochammina inflata (Montagu)

Site Results

A3.1 FORAMINIFERA AND ENVIRONMENTAL VARIABLES

Three sites were selected in the main text for discussion of the relationships between the foraminifera and environmental variables data collected from each site. The remaining data is presented here, with information appearing in Figures A3.1.1 – A3.17.2 in the following site order:

Oban Trumisgarry
Alioter Lagoon
Bac-a-Stoc
Locheport 1
Locheport 2
Grimsay
Pool Roag
Loch na h'airde
Loch of Reiff
Lochan Sal
Loch an Eisg-brachaidh
Loch Roe Lagoon
Oldany Lagoons
Loch Nedd Lagoon
Lochan na Dubh Leitir
Craiglin Lagoon
Dubh Loch

A3.2 Regional Comparison of the Combined Data-set

The screened dataset of 266 samples was split into that from the Hebridean islands of North Uist and Skye (221 samples), and that from the Assynt and Argyll areas of the mainland (45 samples). Values of r (Table A3.1) and r^2 (Table A3.2) were calculated for the relationships in each, and scatter plot matrices calculated in the same manner as for the combined modern dataset (Figures A3.18.1 and A3.18.2). Data from neither region displays any distinct differences from the combined dataset. As a result, the combined dataset is used for the remaining statistical analysis, as there is no apparent gain in treating the results on a regional basis.

	Average Salinity	Maximum Salinity	Salinity Range	Minimum Salinity	Average pH	Minimum pH	pH range	Average temperature	Average Dissolved O^2	% Organic Content	% Clay	% Silt	% Sand	Low tide volume	High tide volume	Basin surface area	Freshwater input	Sill elevation
Average Salinity																		
Maximum Salinity	0.9065*																	
Salinity Range	-0.3766	-0.2392																
Minimum Salinity	0.9037*	0.9303*	-0.5788*															
Average pH	0.6857*	0.6722*	-0.0405	0.5799*														
Minimum pH	0.6710*	0.5750*	-0.0969	0.5195*	0.9297*													
pH range	-0.5858*	-0.5249*	0.1887	-0.5121*	-0.6189*	-0.7690*												
Average Temp	0.4570*	0.4781*	0.2674	0.3005	0.4721*	0.4983*	-0.4873*											
Average Dissolved O^2	-0.3492	-0.4656*	-0.2746	0.2873	-0.3673	-0.3504	0.5203*	-0.8799*										
% Organic Content	-0.3237	-0.3157	0.3653	0.4032*	-0.3260	-0.3880*	0.3987*	0.0294	-0.0188									
% Clay	-0.2140	-0.3340	0.4178*	-0.4384*	-0.1085	-0.1195	0.3858*	-0.0005	0.1651	0.7019*								
% Silt	-0.4193*	-0.4553*	0.5363*	-0.5850*	-0.2845	-0.3237	0.4374*	0.0163	0.0281	0.8655*	0.8898*							
% Sand	0.3744	0.4334*	-0.5168*	0.5592*	0.2444	0.2771	-0.4334*	-0.0123	-0.0647	0.8414*	-0.9381*	-0.9928*						
Low tide volume	0.0530	0.0464	0.1099	-0.0026	0.3658	0.3336	-0.3059	0.1029	-0.1183	-0.1374	0.0226	-0.0838	0.0577					
High tide volume	-0.0559	0.0653	0.3924*	-0.0935	0.3539	0.2329	-0.2322	0.0897	-0.2317	0.0349	0.1044	0.1318	-0.1275	0.8221*				
Basin surface Area	0.0576	0.0322	0.0017	0.0264	0.3289	0.3428	-0.3605	0.0971	-0.0997	-0.2223	-0.0830	-0.1969	0.1713	0.9798*	0.7178*			
Freshwater input	-0.3043	-0.1013	0.6349*	-0.3250	-0.0186	-0.1733	0.1271	0.0223	-0.2379	0.3817*	0.2600	0.4947*	-0.4438*	0.0131	0.5659*	-0.1454		
Sill elevation	-0.2067	-0.2758	-0.0302	-0.2202	-0.2209	-0.1764	0.0093	0.1276	-0.1306	0.0976	-0.0436	0.0099	0.0039	0.5188*	0.1385	0.5877*	0.3682	

Table A3.1: Values of r (Pearson's Correlation Coefficient) for the relationship between environmental variables in the modern dataset for mainland Scotland (Argyll and Assynt). * indicates 99% confidence interval.

	Average Salinity	Maximum Salinity	Salinity Range	Minimum Salinity	Average pH	Minimum pH	pH range	Average temperature	Average Dissolved O^2	% Organic Content	% Clay	% Silt	% Sand	Low tide volume	High tide volume	Basin surface area	Freshwater input	Sill elevation
Average Salinity																		
Maximum Salinity	0.7807*																	
Salinity Range	-0.5950*	0.0038																
Minimum Salinity	0.9530*	0.6195*	-0.7827*															
Average pH	0.3917*	-0.2042	-0.3338*	0.3891*														
Minimum pH	0.4619*	0.1538	-0.4903*	0.4806*	0.8496*													
pH range	-0.4103*	-0.0762	0.5505*	-0.4796*	-0.1864*	-0.6217*												
Average Temperature	0.3449*	0.1848*	-0.3247*	0.3699*	0.4143*	0.4184*	-0.2514*											
Average Dissolved O^2	0.1068	0.0560	-0.1121	0.1293	0.2169	0.1075	0.0297	-0.1075										
% Organic Content	0.3066*	0.2872*	-0.0604	0.2262*	0.0512	-0.0158	0.0741	0.0062	0.1080									
% Clay	0.2849*	0.3294*	0.0189	0.1902*	0.0613	-0.0254	0.1497	0.1099	-0.1158	0.7332*								
% Silt	0.2322*	0.1804*	-0.0661	0.1641	0.1253	0.0566	0.1003	0.0757	-0.0910	0.7168*	0.9322*							
% Sand	-0.2390*	-0.2116*	0.0416	-0.1643	-0.1153	-0.0369	-0.1195	-0.0865	0.0999	-0.7243*	-0.9565	-0.9961*						
Low tide volume	0.0531	-0.0356	-0.0061	-0.0174	0.0579	0.1297	-0.0162	-0.2280*	-0.1189	-0.0872	-0.0402	0.0080	0.0025					
High tide volume	0.0843	0.0019	-0.0093	0.0085	0.0452	0.1171	-0.0167	-0.2418*	-0.1116	-0.0620	-0.0169	0.0251	-0.0159	0.9983*				
Basin surface area	0.0881	0.0387	0.0030	0.0217	0.1925*	0.1383	0.1078	-0.1152	-0.1009	0.0361	0.0961	0.1129	-0.1142	0.8581*	0.8586*			
Freshwater input	-0.1209	0.1093	0.3288*	-0.1901*	-0.0716	-0.2622*	0.4094*	0.3324*	-0.3147*	0.0786	0.3530*	0.2442*	-0.2789*	-0.0789	-0.0776	0.2429*		
Sill elevation	-0.2004*	-0.2699*	-0.0255	-0.1480	0.1106	0.0794	-0.0583	0.1165	0.1612	0.1169	-0.0925	-0.0157	0.0333	-0.6282	-0.6493	-0.5271	-0.2117*	

Table A3.2: Values of r (Pearson's Correlation Coefficient) for the relationship between environmental variables in the modern dataset for the Hebridean Islands of North Uist and Skye. * indicates 99% confidence interval.

Standardised Water Level Index

The altitude of basin sills can not be accurately compared in the statistical reconstruction of relative sea-level without also taking account of their position in relation to the tidal cycle. The altitudes are therefore converted to a standardised water level index (SWLI) from metres OD. Three methods were previously discussed by Horton (1997). Here, the three methods are assessed, in order to find the most appropriate equation for the range of basin elevations in this research:

A4.1 METHOD ONE

The altitude of sills and tide levels are expressed as:

$$x_a = [(\mathrm{A}_a - \mathrm{MTL}_a) / (\mathrm{MHWST}_a - \mathrm{MTL}_a)*100] \tag{7}$$

where A_a is the altitude (m OD) of the sill at site a; MTL_a is the mean tide level (m OD) at site a; MHWST_a is the mean high water spring tide at site a; and x_a is the SWLI of the sill of site a. This method gives values of 0 for the x_a of MTL and 100 for that of MHWST. Figure A4.1 and Table A4.1 show the construction of tide levels using method one.

A4.2 METHOD TWO

The altitude of sills and tide levels are expressed as:

$$x_a = ((\mathrm{A}_a - \mathrm{LAT}_a) / (\mathrm{HAT}_a - \mathrm{LAT}_a)*100) \tag{8}$$

where A_a is the altitude (m OD) of the sill at site a; LAT_a is the lowest astronomical tide (m OD) at site a; HAT_a is the highest astronomical tide at site a; and x_a is the SWLI of the sill of site a. This method gives values of 0 for the x_a of LAT and 100 for that of HAT. Figure A4.2 and Table A4.2 show the construction of tide levels using method two.

A4.3 METHOD THREE

The altitude of sills and tide levels are expressed as:

$$x_a = [((A_a - MLWST_a) / (MHWST_a - MLWST_a)*100) + 100] \quad \textbf{(3)}$$

where A_a is the altitude (m OD) of the sill at site a; $MLWST_a$ is mean low water spring tide (m OD) at site a; $MHWST_a$ is mean high water spring tide at site a; and x_a is the SWLI of the sill of site a. As this method is selected as the most appropriate for the this research, the constant 100 is added to ensure that all values are positive, in order to avoid any potential problems with computer programs and negative values. This method gives values of 100 for the x_a of MLWST and 200 for that of MHWST. Tide level construction is shown in Figure 4.6 and Table 4.3. Table A4.4 shows the construction of the SWLI for sill elevations using method three.

A4.4 SUMMARY

As well as the elevations of tide levels being constructed using each SWLI method in turn (Table A4.2 – Table A4.4), the duration of flooding at Spring tide was also plotted against SWLI using each of the three methods (Figure 4.7 - method three; Figure A4.3 - methods one and two). From this, either method two or method three could be used in this research, as they show the greatest consistency in SWLI values between sites at the different stages of the tide.

Although SWLI method two actually produced a slightly higher value of r^2 and lower RMSE, it was decided to proceed with method three. Method three is based around accurate readings of Spring tides, the data for which is calculated for secondary ports in the Admiralty Tide Tables (2000), whilst method two relies on the accurate measurement of HAT and LAT, the data for which is not calculated for secondary ports in the Admiralty Tide Tables (2000). This requires extrapolation from standard ports, leaving the method open to potentially larger errors in the calculation of the SWLI of each sill.

Site	LAT	MLWST	MLWNT	MTL	MHWNT	MHWST	HAT
Oban Trumisgarry	-140	-105	-45	0	40	100	130
Oban na Struthan	-140	-105	-45	0	40	100	130
Alioter Lagoon	-140	-105	-45	0	40	100	130
Bac-a-Stoc	-140	-105	-45	0	40	100	130
Locheport 1	-140	-105	-45	0	40	100	130
Locheport 2	-140	-105	-45	0	40	100	130
Grimsay	-140	-105	-45	0	40	100	130
Pool Roag	-136.36	-100	-40.91	0	36.36	100	127.27
Loch na h'airde	-166.67	-127.78	-50	0	38.89	100	155.56
Loch of Reiff	-136.36	-104.55	-40.91	0	40.91	100	127.27
Lochan Sal	-136.36	-104.55	-40.91	0	40.91	100	127.27
Loch an Eisg-brachaidh	-136.36	-104.55	-40.91	0	40.91	100	127.27
Loch Roe Lagoon	-163.16	-121.05	-52.63	0	42.11	100	142.11
Oldany Lagoon 1	-157.89	-121.05	-57.89	0	36.84	100	147.37
Oldany Lagoon 2	-157.89	-121.05	-57.89	0	36.84	100	147.37
Loch Nedd Lagoon	-157.89		-57.89	0	36.84	100	147.37
Lochan na Dubh Leitir	-157.89	-121.05	-57.89	0	36.84	100	147.37
Duartmore	-157.89	-121.05	-57.89	0	36.84	100	147.37
Caithlim Lagoon	-107.69	-76.92	-23.08	0	46.15	100	138.46
Craiglin Lagoon	-143.75	-81.25	-62.5	0	56.25	100	125
Dubh Loch	-192.31	-115.38	-115.38	0	69.23	100	153.85
Average	-147.07	108.39	-51.03	0	41.71	100	136.71
SD	16.80	12.86	17.26	0	7.64	0	10.14

Table A4.1: Construction of tide levels using SWLI method one (equation 7).

Site	LAT	MLWST	MLWNT	MTL	MHWNT	MHWST	HAT
Oban Trumisgarry	0	12.96	35.19	51.85	66.67	88.89	100
Oban na Struthan	0	12.96	35.19	51.85	66.67	88.89	100
Alioter Lagoon	0	12.96	35.19	51.85	66.67	88.89	100
Bac-a-Stoc	0	12.96	35.19	51.85	66.67	88.89	100
Locheport 1	0	12.96	35.19	51.85	66.67	88.89	100
Locheport 2	0	12.96	35.19	51.85	66.67	88.89	100
Grimsay	0	12.96	35.19	51.85	66.67	88.89	100
Pool Roag	0	13.79	36.21	51.72	65.52	89.66	100
Loch na h'airde	0	12.07	36.21	51.72	63.79	82.76	100
Loch of Reiff	0	12.07	36.21	51.72	67.24	89.66	100
Lochan Sal	0	12.07	36.21	51.72	67.24	89.66	100
Loch an Eisg-brachaidh	0	12.07	36.21	51.72	67.24	89.66	100
Loch Roe Lagoon	0	13.79	36.21	53.45	67.24	86.21	100
Oldany Lagoon 1	0	12.07	32.76	51.72	63.79	84.48	100
Oldany Lagoon 2	0	12.07	32.76	51.72	63.79	84.48	100
Loch Nedd Lagoon	0	12.07	32.76	51.72	63.79	84.48	100
Lochan na Dubh Leitir	0	12.07	32.76	51.72	63.79	84.48	100
Duartmore	0	12.07	32.76	51.72	63.79	84.48	100
Caithlim Lagoon	0	12.50	34.38	43.75	62.50	84.38	100
Craiglin Lagoon	0	23.26	30.23	53.49	74.42	90.70	100
Dubh Loch	0	22.22	22.22	55.56	75.56	84.44	100
Average	0	13.57	34.01	51.74	66.49	87.23	100
SD	0	3.10	3.16	2.06	3.23	2.54	0

Table A4.2: Construction of tide levels using SWLI method two (equation 8).

Site	LAT	MLWST	MLWNT	MTL	MHWNT	MHWST	HAT
Oban Trumisgarry	82.93	100	129.27	151.22	170.73	200	214.63
Oban na Struthan	82.93	100	129.27	151.22	170.73	200	214.63
Alioter Lagoon	82.93	100	129.27	151.22	170.73	200	214.63
Bac-a-Stoc	82.93	100	129.27	151.22	170.73	200	214.63
Locheport 1	82.93	100	129.27	151.22	170.73	200	214.63
Locheport 2	82.93	100	129.27	151.22	170.73	200	214.63
Grimsay	82.93	100	129.27	151.22	170.73	200	214.63
Pool Roag	81.82	100	129.55	150.00	168.18	200	213.64
Loch na h'airde	82.93	100	134.15	156.10	173.17	200	224.39
Loch of Reiff	84.44	100	131.11	151.11	171.11	200	213.33
Lochan Sal	84.44	100	131.11	151.11	171.11	200	213.33
Loch an Eisg-brachaidh	84.44	100	131.11	151.11	171.11	200	213.33
Loch Roe Lagoon	80.95	100	130.95	154.76	173.81	200	219.05
Oldany Lagoon 1	83.33	100	128.57	154.76	171.43	200	221.43
Oldany Lagoon 2	83.33	100	128.57	154.76	171.43	200	221.43
Loch Nedd Lagoon	83.33	100	128.57	154.76	171.43	200	221.43
Lochan na Dubh Leitir	83.33	100	128.57	154.76	171.43	200	221.43
Duartmore	83.33	100	128.57	154.76	171.43	200	221.43
Caithlim Lagoon	82.61	100	130.43	143.48	169.57	200	221.74
Craiglin Lagoon	65.52	100	110.34	144.83	175.86	200	213.79
Dubh Loch	64.29	100	100.00	153.57	185.71	200	225.00
Average	81.36	100	127.45	151.83	172.00	200	217.49
SD	5.53	0	7.70	3.16	3.49	0	4.12

Table A4.3: Construction of tide levels using SWLI method three (equation 3).

Site	Sill Altitude (m OD)	SWLI
Oban Trumisgarry	0.813	165.93
Oban na Struthan	0.851	166.85
Alioter Lagoon	0.674	162.54
Bac-a-Stoc	0.653	162.02
Locheport 1	0.879	167.54
Locheport 2	0.417	156.28
Grimsay	1.035	171.34
Pool Roag	-0.707	125.52
Loch na h'airde	1.851	191.49
Loch of Reiff	1.426	177.24
Lochan Sal	3.182	216.26
Loch an Eisg-brachaidh	0.801	163.36
Loch Roe Lagoon	0.477	154.21
Oldany Lagoon 1	1.42	179.05
Oldany Lagoon 2	1.923	191.02
Loch Nedd Lagoon	1.921	190.98
Lochan na Dubh Leitir	4.498	252.33
Duartmore	-0.546	132.24
Caithlim Lagoon	1.084	170.61
Craiglin Lagoon	1.417	180.59
Dubh Loch	1.193	182.61

Table A4.4: Sill elevations and SWLI values, using SWLI method three.

WA-PLS Calibration and Modern Analogue Technique Results for Fossil Data

This appendix provides data not included in Chapter Six for WA-PLS calibration and Modern Analogue technique tests on fossil data from two basins.

The data are presented are:

i. Dubh Lochan. WA-PLS calibration (Table A5.1 and Figure 6.9).
ii. Loch nan Corr. WA-PLS calibration (Table A5.2 and Figure 6.10).
iii. Loch nan Corr. MAT (Table A5.3 and Figure 6.10).

Sample Number	Sample Depth	PLS Predicted Salinity
1	122	15.71
2	126	15.71
3	134	18.79
4	142	17.41
5	150	17.95
6	158	16.59
7	166	16.95
8	174	16.93
9	182	18.87
10	190	22.52
11	198	23.62
12	206	23.51
13	214	22.27
14	222	21.22
15	230	21.60
16	238	18.61
17	242	23.26
18	246	25.98
19	248	27.14
20	250	28.81
21	252	27.50
22	254	26.41
23	262	26.04
24	266	26.00
25	269	26.06

Table A5.1: Summary of salinity values predicted for samples in a fossil core from Dubh Lochan basin, Coigach.

Sample Number	Sample Depth	PLS Predicted Salinity
1	104	16.09
2	112	16.40
3	120	17.45
4	128	27.19
5	136	26.78
6	144	27.48
7	160	28.01
8	176	27.70
9	192	27.43
10	208	27.69
11	224	27.26
12	240	27.28
13	256	27.26
14	272	26.09
15	288	27.42
16	304	27.39
17	328	26.71
18	336	26.40
19	344	27.62
20	352	28.01
21	360	28.01
22	368	28.01
23	376	28.01
24	384	28.53
25	400	28.24
26	424	25.17
27	432	27.02
28	440	25.22
29	448	26.52
30	456	27.90
31	464	27.33
32	472	27.88
33	480	26.61
34	490	28.52
35	500	28.22
36	520	28.67
37	540	28.71
38	560	28.86
39	580	28.88
40	600	29.41
41	620	29.75
42	630	29.54
43	646	29.12
44	662	29.15
45	678	28.61
46	686	29.20
47	694	30.13
48	702	29.67
49	710	29.45
50	718	30.04
51	726	30.63
52	730	30.07
53	738	28.62
54	746	28.45
55	754	26.55
56	758	27.80
57	762	28.36
58	766	28.54

59	770	28.50
60	774	28.96
61	778	28.96

Table A5.2: Summary of salinity values predicted for samples in a fossil core from Loch nan Corr basin, Kintail.

Sample	Depth	PLS Calibration	Weighted Mean	Min DC	Analogue
1	5	-	20.17	2.0000	No Close
2	26	-	20.17	2.0000	No Close
3	50	-	20.17	2.0000	No Close
4	66	-	20.17	2.0000	No Close
5	72	-	16.76	2.0000	No Close
6	80	-	21.41	2.0000	No Close
7	88	-	20.17	2.0000	No Close
8	96	-	27.12	2.0000	No Close
9	104	16.09	18.41	0.4784	No Close
10	112	16.4	21.22	0.0594	No Close
11	120	17.45	21.32	0.0644	No Close
12	128	27.19	21.58	1.2105	No Close
13	136	26.78	21.55	1.0755	No Close
14	144	27.48	21.62	1.2741	No Close
15	160	28.01	23.55	1.4523	No Close
16	176	27.7	23.38	1.3256	No Close
17	192	27.43	21.60	1.2381	No Close
18	208	27.69	23.37	1.3106	No Close
19	224	27.26	21.59	1.2425	No Close
20	240	27.28	21.62	1.2933	No Close
21	256	27.26	21.59	1.2282	No Close
22	272	26.09	21.21	0.9453	No Close
23	288	27.42	23.31	1.2980	No Close
24	304	27.39	21.60	1.2301	No Close
25	328	26.71	21.62	1.0530	No Close
26	336	26.4	21.21	1.0020	No Close
27	344	27.62	23.34	1.3137	No Close
28	352	28.01	23.55	1.4523	No Close
29	360	28.01	23.55	1.4523	No Close
30	368	28.01	23.54	1.4686	No Close
31	376	28.01	23.55	1.4523	No Close
32	384	28.53	26.21	0.8917	No Close
33	400	28.24	26.18	0.8284	No Close
34	424	25.17	26.78	0.2976	No Close
35	432	27.02	26.36	0.3269	No Close
36	440	25.22	21.51	0.6283	No Close
37	448	26.52	26.94	0.4302	No Close
38	456	27.9	28.02	0.2528	No Close
39	464	27.33	26.64	0.3418	No Close
40	472	27.88	26.85	0.3598	No Close
41	480	26.61	26.24	0.6372	No Close
42	490	28.52	28.46	0.1459	No Close
43	500	28.22	27.67	0.2328	No Close
44	520	28.67	28.21	0.1712	No Close
45	540	28.71	28.21	0.1581	No Close
46	560	28.86	28.04	0.1654	No Close
47	580	28.88	27.92	0.2181	No Close
48	600	29.41	28.26	0.5781	No Close
49	620	29.75	29.81	0.6630	No Close
50	630	29.54	27.99	0.7724	No Close
51	646	29.12	25.30	0.7951	No Close
52	662	29.15	26.29	0.6828	No Close
53	678	28.61	27.04	0.7124	No Close
54	686	29.2	26.77	0.5382	No Close
55	694	30.13	27.81	0.6603	No Close
56	702	29.67	28.05	0.7290	No Close

57	710	29.45	26.42	0.6479	No Close
58	718	30.04	26.73	0.6583	No Close
59	726	30.63	28.94	0.8429	No Close
60	730	30.07	27.01	0.8183	No Close
61	738	28.62	27.11	0.6634	No Close
62	746	28.45	27.17	0.3619	No Close
63	754	26.55	27.08	0.3907	No Close
64	758	27.8	27.15	0.4693	No Close
65	762	28.36	27.63	0.2585	No Close
66	766	28.54	27.70	0.2560	No Close
67	770	28.5	28.53	0.1217	No Close
68	774	28.96	26.89	0.4068	No Close
69	778	28.96	26.89	0.4068	No Close

Table A5.3: MAT Assessment of PLS Calibration predictions for samples from Loch nan Corr fossil isolation basin, Kintail. No samples have a DC (Dissimilarity Coefficient) lower than the 20th percentile (Table 6.6) and, therefore, there are no good analogue samples for this fossil data in the modern training set.